Volume 21 SEPTEMBER, 1937 Number 9

BULLETIN
of the
American Association *of* Petroleum Geologists

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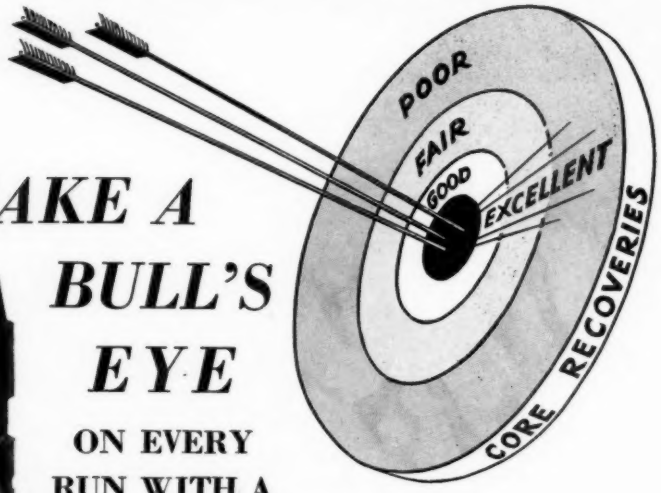

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THE SUBSCRIPTION PRICE to non-members of the Association is $15.00 per year (separate numbers $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

British agent: Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4.

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Entered as second-class matter at the Post Office of Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

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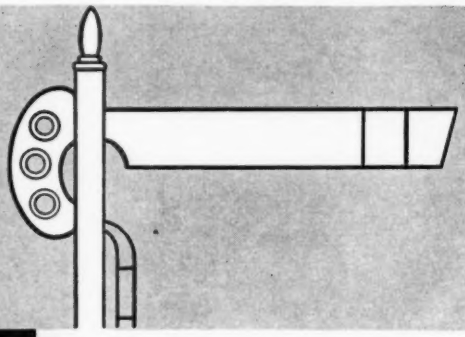

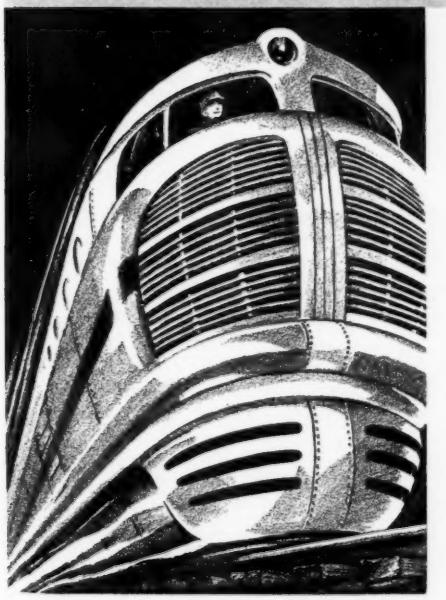

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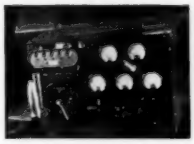

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Volume 21 Number 9

BULLETIN
of the
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SEPTEMBER, 1937

SEDIMENTATION IN BARRED BASINS, AND SOURCE ROCKS OF OIL[1]

W. G. WOOLNOUGH[2]
Canberra, F.C.T., Australia

ABSTRACT

While the DOCTRINE OF UNIFORMITY must always form the basis of geological theory, it is necessary to admit that phenomena have occurred during geological time which have not been observed at all, or not in their entirety, during the very limited period of modern scientific investigation.

Reasons are given for the belief that major coal measures, major primary salt deposits, major fresh-water series of sediments, and source rocks of oil deposits are not now being deposited anywhere on the earth.

No continent-wide peneplanation of advanced maturity, comparable, for example, with the Middle Tertiary peneplanation of Australia, can be recognized at the present day. It is believed that the present is largely a period of orogeny rather than of peneplanation.

It seems probable that periods of greatly enhanced humidity and of greatly enhanced aridity, and others of wide temperature fluctuations, have marked many eras in the geological past, and have left their impress on sediments formed during such eras. The present condition of the earth can not be assumed to be the only "normal" one in earth history. In cases where the characteristics of geological formations require explanations other than those afforded by the strict application of the Doctrine of Uniformity it is legitimate and necessary to invoke causes not now observed in operation, provided always that *objective evidence*, not conformable with conventional explanations, can be adduced.

The close relationship between sediments and their environment has been emphasized by Twenhofel, and the fossil contents of such sediments generally but not always conform with this environment. The grade of this relationship under different circumstances is discussed in some detail.

It is insisted that under normal conditions of deposition in any environment there should be preserved a BALANCED ASSEMBLAGE of fossil forms, including benthos, nekton, and plankton in suitable proportions. Any *unbalance* of assemblage indicates something abnormal in conditions of deposition, and demands explanation.

The main thesis of this paper is an amplification of the "Bar Theory" of Ochsenius. It is suggested that, when all implications of this theory are considered, the possibility is indicated of existence in the geological past of "barred basins" of dimensions and characters entirely unrepresented at the present day.

Reasons are given for associating barred basins chiefly with maturity of peneplanation. Climatic factors are considered and it is concluded that humidity favors development of lacustrine conditions, of coal, boghead, and oil shale; while aridity

[1] Manuscript received, April 22, 1937.

[2] Geological adviser to the Commonwealth Government.

controls formation of black shales, source rocks of oil, and ultimately salt deposits. Certain characteristics are common to all such deposits.

The occurrence of unbalanced planktonic assemblages of fossils, generally erroneously interpreted as indicating *pelagic* conditions, is shown to be compatible with deposition in barred basins. Fineness of texture and lamination, blackness of shale deposits, high organic content, pyritization, and composition of oil-field waters are believed to be due to barred-basin environment and not to excessive depth of water.

The suggestion is put forward, merely as a suggestion at this stage, that certain lithological characters and structural features may be genetically associated with such depositional environments. Amongst these may be mentioned concretionary structure, cone-in-cone, barren argillaceous limestones, and organic siliceous cherts, particularly if dark in color.

The relations of barred-basin deposits with the "euxinic facies" of van der Gracht, and the "sargasso environment" of Ruedemann are discussed.

As possible examples of deposits of barred basins are cited the saline formations of New Mexico, Irwin River basin (Western Australia), "shoestring sands" of Kansas and Oklahoma, Cretaceous limestones of Venezuela, Yates pool (Texas), some of the formations of southern California, and black shale deposits of New York and elsewhere.

DOCTRINE OF UNIFORMITY

One of the most fundamental conceptions in geology is that great generalization, largely formulated by Sir Charles Lyell, to which is applied the name of the "DOCTRINE OF UNIFORMITY." Without this, the development of geology as a science could not have taken place. Essentially, it insists that the present is the key to the past, and that it is through an understanding of those geological processes at present in action that we must approach all attempts to elucidate the geological history of the past.

While this is undoubtedly so, as a generalization, the possibility of exceptions must not be neglected. The too close and restricted application of this Doctrine, as though it were an immutable and all embracing Law of Nature, has been the cause of the development in geological thought and literature of many dogmas and shibboleths which have become so deeply embedded in the science as almost to defy eradication. Yet the advance of knowledge shows from time to time that some even of the most cherished landmarks of the science must be changed or demolished. There appears to be developing a healthy spirit of inquiry into geological foundations which is all to the good. Reaffirmation of well known laws, after critical examination and searching analysis, will make the laws themselves more stable than ever as a sure foundation for the growing superstructure of science. On the other hand, the discovery of weaknesses and flaws necessitates re-statement and modification if the development of serious weaknesses and collapses in the superstructure are to be avoided.

Most geologists will exclaim against the suggestion that they are blind to the possibility of limitations in the application of the Doctrine of Uniformity, and will claim, always in perfectly good faith, that their minds are open to all the implications of such limitations. Yet,

in almost any paper which one selects at random, critical analysis will reveal explicit or implicit re-statement of the limited Doctrine of Uniformity. This sometimes, though of course not always, leads to failure to appreciate *some* of the implications of the facts available.

Taking random examples from recent papers by leaders in geological thought, of whose ability and freedom from conservatism there can be no possible doubt, van der Gracht (8)[3] states (translation, W.G.W.):

> The investigations [of Trask] are dominated by the fundamental conception that all geological processes in the past are not fundamentally different from those which are still active at the present day, and that therefore the study of existing phenomena of sedimentation must supply the key to the problem of genesis of fossil petroleum and its related gases, provided these substances are sedimentary in character as is believed by the vast majority of investigators.

Twenhofel (23, p. 459) says:

> It would seem unnecessary to state that the environmental conditions in any large body of water would be of wide range with corresponding ranges in the variety of sediments deposited and organisms dwelling on the bottom. This is the case now and it is most reasonable to assume that *every* large body of water of past geological periods possessed a wide range of environmental conditions and deposited sediments and supported a flora and fauna commensurate with the environmental range. (Italics, W.G.W.)

Such statements, perfectly correct in their immediate context, represent the explicit statement of the limited Doctrine of Uniformity, and do not suggest a complete admission of the possible existence, in past geological periods, of sets of conditions vastly and fundamentally different from those prevailing at the present time.

The monumental work of Trask (22) is also an explicit assumption of the application of the strict Doctrine of Uniformity.

Twenhofel (23, p. 466) says:

> Conclusions respecting source materials based on analyses of *raw sediments* are considered of little value in postulating the environments in which petroliferous substances accumulate, as these *raw materials* at a depth of several feet may be altogether unlike the appearance at the surface and may have entirely lost their entire content of organic matter. The problem of source materials *can only be solved by studies of sediments* collected beneath the surface at depths and under conditions precluding further work of destructive micro-organisms. (Italics in last sentence only, W.G.W.)

Here the insistence on the rigid application of the Doctrine of Uniformity is implicit rather than explicit; but the limitation is none the less definite.

[3] Figures in parentheses indicate references at end of article.

A little consideration will indicate that this, generally unconscious, limitation of conditions can not be universally maintained.

The writer was engaged for a number of years in an intensive investigation of salt deposits, in the course of which he studied the literature carefully, and visited arid regions where, if anywhere, such deposits should have been observed in course of formation. In no instance were conditions encountered which could conceivably have produced any of the *major* primary salt deposits of the geological past. *Some* circumstance or set of circumstances, entirely lacking under present day conditions, *must* have been operative when such major salt deposits were generated.

Again, nowhere in the world, at present, can accumulations of vegetable matter be found which are *quantitatively* commensurate with any of the major coal deposits of past geological time. Potonié and others have carried out magnificent researches which have indicated a *qualitative* analogy between the peat accumulations of sub-Arctic regions of the present, and coal deposits of the past, at least so far as the *autochthonous* coals are concerned. In the problem of genesis of the great coal measures, however, there are outstanding many problems insoluble by the strict and limited application of the Doctrine of Uniformity.

Other examples are afforded by the evidences of widespread glaciation at various eras in the past, by the enormous development in some periods of epicontinental formations which have no counterpart at the present time, and by many other phenomena which spring to the mind.

Amongst these the writer sees the genesis of source rocks of petroleum. Much as he appreciated the great work of Trask and his collaborators, he agrees with Twenhofel that the conditions under which the sediments analyzed by Trask have been deposited preclude the possibility of their being regarded as potential source rocks for petroleum.

A little consideration will suggest that the view that man, and particularly civilized and scientific man, has had the opportunity of viewing directly *all* the formative processes of geology is against all mathematical probability. Our truly scientific observation of nature's processes extends over less than two centuries, while nature has been at work modifying the earth's accessible crust for not less than a thousand million years. It is inconceivable that the entire range of possible modifications has been covered within the insignificant portion of time during which scientific observation has been carried on.

This is brought home to us, at intervals, by such phenomena as

those of the eruption of Mont Pelée in Martinique, when the extrusion of the "Spire of Pelée" and the destruction of St. Pierre by a cloud of incandescent dust (the "ignimbrite" of Marshall) opened up new vistas of possibilities in the study of vulcanology, which is, in its very nature, one of the oldest branches of geological observation and research.

It follows, then, that occasional excursions into the unknown seas beyond the limits of those plumbed and charted by the rigid Doctrine of Uniformity are more or less legitimate. It is not contended that such excursions should be of the nature of uncontrolled flights of fancy. On the contrary, while a certain amount of "prophetic vision" and "constructive imagination" may be indulged in, the canons of scientific thought demand that, at every point, such tentative speculations shall be submitted to the strict arbitrament of fact and experimental proof. *Only* so far as the speculations are found to measure up to this standard is it legitimate to use them as the premises for further reasoning.

It may be that, from time to time, it becomes necessary to take a plunge into the darkness and to make some tentative assumption for which no objective analogy can be obtained. Probably some of the greatest advances in scientific generalization, such as the beginnings of the Laws of Gravitation, have been founded on such intuitions; and leaps in the dark by great pioneers must be admired by all, though they can not safely be emulated by any but the occasional genius.

It is far commoner, however, particularly in geology, for the germs of an idea to be suggested by some objective phenomenon, which, while qualitatively incomplete and quantitatively inadequate, may nevertheless direct the mind of the searcher into some profitable channel of speculation and deduction.

The writer would therefore ask to be permitted to advance three postulates: (1) the geological processes active in the world at the present day represent only a fraction of the processes which have acted, throughout geological history, in modifying the earth's crust; (2) existing phenomena are capable of extension, both qualitatively and quantitatively, to account for results which defy explanation by the strict application of the Doctrine of Uniformity; (3) processes may be envisaged which have no counterpart at present, provided that the assumptions so made are not contrary to the fundamental laws of nature, and that there can be found objective instances explicable by such assumptions only and by no recognized and accepted phenomena.

The object of this paper is to submit for consideration, and for modification or refutation as may be required, certain suggestions which have occurred to the writer during the last 30 years, as possible means of explaining some of the apparent paradoxes and contradictions which seem to exist in relation to the probable conditions of accumulation of some important types of sedimentary deposits. Most, probably all, of these ideas have been advanced by others from time to time; but the writer has never seen any complete and consecutive account of the suggestions here advanced. This is possibly because, for many years, he has been so situated that ready access to extensive geological libraries has not been possible. If, then, views are put forward without acknowledgment of their authorship, this is done in ignorance, and sincere apologies are offered to all concerned.

It is believed that some characteristics can be observed which are common to such widely diversified deposits as certain graptolite shales of the Lower Paleozoic, the world's great coal deposits, primary major salt beds, and source rocks of petroleum; and which all point to the former existence of a set of conditions of accumulation not now exhibited, on a major scale, in any part of the world. To enter upon this discussion, it is desirable to recapitulate very briefly some of the outstanding factors which govern the accumulation of present day marine and fresh-water deposits, and which determine the presence or absence, and the nature of the fossil contents of such deposits.

SEDIMENTATION

Twenhofel (23) rightly insists that sediments are very sensitive to the environment in which they are deposited, and that many of the conceptions which have become firmly entrenched in geological thought and literature will require modification in the very near future.

Broadly speaking, the mineralogical character of mechanically formed sediments is determined by the rock source from which they are derived, modified profoundly by the chemical changes which occurred prior to or subsequent to deposition, and by mechanical sorting, chiefly by running water, dependent largely on the specific gravity, size, and shape of the individual grains.

While modern research has shown that there are many local exceptions to the rule that psephites and psammites (pebbly and sandy rocks) were deposited near shore, while pelites (clay rocks) were deposited in deep water, such a rule does actually represent a first approximation, the local deviations being explicable chiefly by variations in the strength of currents. Thus, broadly, littoral sediments are

dominantly sandy, continental-shelf mechanically formed sediments are ***dominantly*** clayey, and abysmal sediments are almost exclusively fine-grained. Each individual case, however, must be considered on its merits, and *all* facts must be taken into account in determining the probable environment of the deposit.

Very rarely are marine deposits laid down which are not associated with organic life in some form or other. Considering how prolific is the vegetable and animal life in normal sea water, the quantity of organic matter met with by Trask (22) and by the Danish workers (16) in their chemical investigations of sea-bottom deposits is amazingly small.

Van der Gracht states (9) that two thousand samples from all parts of the world were found by Trask to contain on the average only 2.5 per cent organic matter. Pelagic sediments contain about 0.75 per cent, and the richest only about 1.5 per cent. The original organic content of the oil-bearing sediments at Santa Fe Springs, California, is not less than 3 per cent.

In the euxinic muds of the Black Sea the organic matter amounts to 25–35 per cent.

In considering the quantity of organic matter met with in marine sediments, we must take cognizance of the distribution of the living matter in the water, the conditions under which death takes place, and the factors attending its deposition and entombment.

ORGANIC MATTER IN THE OCEAN

Organic matter is distributed in the ocean in three distinct categories, namely, as plankton, nekton, and benthos, and each of these requires different conditions of environment, both during life and after death, if it is to leave any permanent record of its existence in the rocks which build up the geological record.

Plankton consists of those organisms which float freely and inertly in the upper, well aërated, sunlit layers of the sea. Its habitat is practically independent of the nature of the sea bottom, but is governed by such factors as the temperature and salinity of the water, and the abundance and nature of the food supply. Incapable of controlling their movements to any extent, plankton organisms are distributed almost entirely by ocean currents, which, in turn, are profoundly influenced by winds. Since winds and currents are determined ultimately by solar heat, and by terrestrial rotation and the shape of the earth, it seems probable that, ever since the oceans existed, there have been certain fundamental laws of distribution of plankton. Of course, ocean currents are profoundly modified, both in position and

intensity, by such temporary and local factors as polar ice caps and land barriers, so that no universal law can be stated.

Plankton may live and die, generation after generation, without removal from its normal habitat, and some of the remains may sink gradually to the sea bottom, to mingle with the other accumulations there forming. Under "normal" conditions a very small fraction only of the organic matter can possibly be preserved in this way. Plankton consists of organisms most of which are microscopic or exceedingly small and devoid of hard parts. Their protoplasmic material quickly decomposes and oxidizes in the highly aërated surface waters, or is eaten before or immediately after death by other organisms.

Only in very exceptional circumstances, to be considerd later, can any considerable fraction of this protoplasmic material be permanently perserved.

Owing to the low specific gravity of the material, and to its high ratio of surface to volume in many cases, the sinking of planktonic material may be exceedingly slow. There is, therefore, a probability of very extensive drift between the native habitat of the organisms and their final resting place. In absence of other criteria, the presence of planktonic types of fossils can not, therefore, be relied on in determining the environment of deposition of the sediments in question.

Many, probably most, of the plankton forms are very sensitive to such environmental factors as salinity, temperature and turbidity of the water. Hence if, in the course of drift, they are introduced into a hostile environment, they perish in vast numbers and in short time. It becomes possible, then, for planktonic forms to be encountered in the fossil state in prodigious numbers on limited horizons, while they are scanty or absent in beds above and below. The density of the killed plankton may be such, in extreme instances, as to upset the chemical equilibirum in the superficial waters, causing complete absorption of the available oxygen for the time being, and developing an oxygen deficiency favorable to the preservation of organic compounds which are, in general, completely and rapidly destroyed under more normal circumstances.

Nekton includes those organisms possessed of independent motive powers, which can swim more or less freely, and which can, therefore, of their own volition, select their environment within limits. They are actuated by powerful tropisms which cause them to move in search of food and of comfortable surroundings, and to shun conditions which are distasteful in any particular. They are therefore intermediate between plankton and benthos in their dependence on environment.

Some nektonic forms which live on plankton are so closely associated with the latter as to have practically identical limits of distribution. Other types whose food consists of bottom-living organisms, have their affinities in definitely limited environments, controlled eventually by the mineral and textural (inorganic) characteristics of the materials of the local sea floor. Nekton fossils may therefore be expected both with plankton and with benthos assemblages.

While the movements of the free-swimming organisms are to a large extent under their own control, it must be remembered that such movements are relative only in their ultimate results. Fish, for example, move more or less rapidly through the water in which they are immersed; but if the whole body of water is itself in motion, the actual translation of the organisms is the resultant of the combined velocities involved.

The degree to which fossils of nekton types indicate environmental conditions is therefore notably variable, and the greatest caution is necessary in employing them as environmental indicators.

Benthos comprises organisms living on and in the sea bottom. Some of these organisms are sessile, attached immovably to the bottom during life and after death. Other forms have limited powers of locomotion, active or passive, and there is no strict demarcation between benthos and nekton.

The degree of dependence of sessile organisms on the nature of the inorganic materials to which they are attached, varies within wide limits; but, generally speaking, the association is very intimate. Many forms are absolutely dependent on the physical character of the materials of the local sea floor, and can not continue to exist in any other environment. Such forms provide food and shelter for others, and a long chain of dependence is forged, the extent and ramifications of which may be enormous and unpredictable. This mutual dependence, founded ultimately on the nature of the bottom materials, but involving such complex physical factors as depth, temperature, salinity, hydrogen ion concentration, illumination, turbidity, topography of surrounding areas of the sea floor, oxygen supply, distribution of ocean currents, and many more, imposes a very rigid control on the nature of assemblage of co-existing organic forms. For each particular limited region of the sea floor there is a strictly limited assemblage of organic forms, and the facies of this assemblage varies, sometimes gradually, sometimes with remarkable suddenness, from place to place (Twenhofel, 23; Walther, 26; *et al.*).

While the chances of preservation in fossil form, of a relatively

considerable proportion of the organisms in a given locality is greater for benthos than for nekton or plankton, the factors controlling such chances of preservation are many and complex. Naturally, it is impossible to expect, anywhere or at any time, an even moderately complete fossil record of the entire organic assemblage. Plants and animals devoid of hard parts can be represented in the fossil state only by impressions and casts even in the most favorable circumstances. Generally they disappear and leave no trace whatever of their existence. Organisms with hard parts can be preserved in any of the well known ways, but, under *normal* conditions, with entire removal of soft parts and generally also of the more fragile portions of the hard parts as well.

All *normal* portions of the sea bottom are well supplied with oxygen, even in abysmal depths. Protoplasm is thereby readily oxidized, and decomposed into its gaseous and soluble constituents. As Cunningham Craig points out, the greater part of the organic matter is eaten alive by the carnivorous and herbivorous inhabitants of the water. Scavenging organisms, which are present in enormous numbers on the bottom and in the mud or sand of the upper layers of the sea floor, deal with the residue of the organic matter, and even work over and over again the excrement of the higher forms. Aërobic bacteria abound in the aërated water, and on and under the bottom, and there complete the work of degeneration of the more complex organic molecular material. This explains how it is that the quantity of organic material recorded by Trask and the Danish workers from normal marine sediments is so surprisingly low.

Wepfer (28) has shown that the optimum conditions for preservation of a relatively complete record of marine life in the fossil condition are encountered where there is a delicately adjusted balance between abundance of organisms and rapidity of accumulation of sediment. Absence of inorganic sediment favors abundance of life, but provides poor conditions for entombment. Excessive sediment, on the other hand, reduces viability, but favors entombment. The most essential point to be remembered is that, *under normal marine conditions*, the assemblage of organisms at any one time and place is a BALANCED ASSEMBLAGE, in strict equilibrium with the environment. Any disturbance of this delicately poised equilibrium is followed immediately by an alteration in the nature of the assemblage, more or less conspicuous in direct ratio to the character and extent of the variation of the dominant factors of environment. If, then, the impact of environmental factors is adequately known, it is possible to trace the nature of the consequential changes, even of very ancient forma-

tions, and to deduce many vital factors in relation to paleogeography.

The existence at any time or place of an *unbalanced assemblage* of organic forms is proof positive of serious disturbance of equilibrium, points to definite abnormality of conditions, and demands explanation. Such explanation may require the postulation of permutations and combinations of factors not anywhere operative at the present day.

Twenhofel has done good service in emphasizing the fact that there is no necessity, in every case, to invoke major crustal oscillations to account for even pronounced changes in faunal facies. If the main thesis of the present paper is correct, the writer hopes to suggest that, by a legitimate departure from the strict Doctrine of Uniformity, it is possible to visualize certain structural features, unrepresented or poorly represented at the present day, which call for only slight and insignificant tectonic causes to account for relatively profound variations in faunal facies, and for the development of violently unbalanced assemblages, under conditions which may serve to throw light on the genesis of at least some occurrences of source rocks of petroleum, coal, and salt.

No part of the normal sea bottom is entirely free from benthos, though there are enormous differences in its density. Even abysmal depths support their own *balanced* assemblages and it is questionable whether there exist anywhere at present areas *in the open sea* entirely untenanted by organisms. It is well known that the relatively shallow, well illuminated waters covering continental shelves in tropical and subtropical latitudes carry the most prolific organic life, both qualitatively and quantitatively. Abundance of life exists, however, even up to the base of the Great Ice Barrier of the Antarctic Continent, and differs more in kind than in quantity from that of more temperate regions. The widespread belief that low temperature *per se* is inimical to life is contrary to fact.

The central oceanic abysses, far beyond the reach of the faintest glimmer of sunlight, with water temperatures monotonously regular at about 4°C. over enormous areas, support an organic assemblage nourished chiefly on the rain of material from deceased organisms inhabiting the illuminated zones nearer the surface. This abysmal life depends for its oxygen on the equatorward creep of bottom waters which sink downwards in polar regions. At present, this circulation is profoundly influenced by the position and magnitude of the polar ice caps. In other eras, when polar ice was insignificant or absent, such a source of oxygenation of the water of abysmal depths may not have been so effective; but it is a moot point whether this circulation is

not to be regarded as cosmic rather than geographic—a direct result of the earth's shape and relation to the sun affected only quantitatively by variations in terrestrial climate and geography.

Important variations in environmental conditions are imposed by the topography of the ocean bottoms and particularly by the contiguity of subaërial land surfaces. The question of submarine topography is treated in greater detail in following paragraphs.

Particularly around continental masses of land the nature of both inorganic sediments and of their organic contents is profoundly modified by the accession of material brought down by rivers, supplied and distributed by ocean waves and currents, and blown in by winds. The character and amount of such accessions is determined by the geological nature, topography, and climate of the land areas, and study of the sediments formed in adjacent basins provides the chief basis for determination of the paleogeography of any region.

In *open sea* near continental margins the chief effects of subaërial conditions on the organisms preserved as fossils are due to the abundance of supply of mineral matter for relatively rapid entombment, and to contributions to food supplies of organic matter derived from land plants and animals. The latter introduce also an admixture of remains of land plants and animals which locally may become important as fossils, though usually such admixture remains entirely subordinate.

It is chiefly in more or less enclosed basins around continental margins that the greatest modifications of the marine environment occur, and, in such situations, the effects may be profound.

TYPES OF CLOSED BASINS

The principal thesis of this paper is that the geological formations of many past ages exhibit characteristics which can be explained *only* on the assumption that closed-basin conditions existed at the time of their deposition, and were of a nature and extent essentially different from those of any existing basin. Therefore, in the investigation of them a departure from the strict and limited applications of the Doctrine of Uniformity is essential.

True, there exist around all continental margins enclosed and partially enclosed basins of many different types, some of them of very notable dimensions. The Mediterranean Sea, Black Sea, Red Sea, Persian Gulf, Baltic Sea, Caribbean Sea and Gulf of Mexico, Hudson Bay, Gulf of St. Lawrence, Sea of Japan, Sea of Okhotsk, Behring Sea, Arafura Sea, Banda Sea, and other enclosed basins in the East Indies, all are examples of *major* basins more or less com-

pletely cut off from the open ocean. In every instance the equilibrium of environmental conditions within the basin is somewhat different from that in near-by portions of the open ocean, but in very few instances is there a complete contrast between oceanic conditions and basin conditions.

The more nearly complete the severance from the ocean, the greater is likely to be the contrast between the sediments of adjacent areas and their organic contents. In some instances, as in the Baltic Sea, the accession of fresh water from the continental surface is so great as to lower appreciably and permanently the salinity of the sea water. This automatically excludes a vast range of organic types capable of flourishing in open seas of similar latitudes; but it does not preclude the development of a prolific and thoroughly balanced specialized assemblage. Probably no region in the world has been more completely examined than has the Baltic Sea, largely as a result of the activities of the Danish scientific workers (13,16), to whom we are indebted for many far-reaching generalizations in connection with the physics, chemistry, and biology of marine accumulations.

In other instances, of which the Red Sea may be taken as the type, the climatic conditions of the adjacent continental lands result in practical inhibition of river action, high temperature, and excessive evaporation, so that the sea water attains a salinity in excess of that of ocean water. Even in this case, however, biological adaptation is still functional, and a specialized but nevertheless *balanced* assemblage of organisms inhabits the waters and the sea floor.

Of the other basins mentioned, some are tropical, some are arctic; some are in humid, some in arid regions; some are separated from the ocean only by deeply submerged ridges, others are nearly cut off by continental lands. Yet, with one notable exception, the Black Sea, the organic assemblages in all the basins are essentially balanced, so far as the writer's admittedly very incomplete study of the literature shows. In the deposits laid down on their floors are entombed and preserved remains of their characteristic benthos, mingled with larger or smaller proportions of adventitious nekton and plankton fractions and with remains of plants and animals derived from the adjacent continental lands or oceanic islands. The forms so fossilized will always serve as a criterion for determining within narrow limits the geographical environment of the sedimentation. Arguing on the limited Doctrine of Uniformity, comparisons between the deposits of such areas and those of past geological ages should enable us to deduce paleogeographic conditions then existing with considerable confidence.

In practically every instance the balanced faunal assemblage in such basins contains its quota of scavenging forms, so that the destruction of protoplasmic matter is as complete as it is in *normal sea water*. The waters are aërated and the action of aërobic bacteria is complete. The sediments deposited in such basins exhibit that remarkable freedom from organic matter which has been demonstrated by Trask and the Danish school.

The highly anomalous case of the Black Sea is discussed in greater detail in suceeding paragraphs.

Smaller inlets on continental margins are infinite in number and variety. The greater part of our knowledge of littoral sedimentation and fossilization has been obtained from investigations in such localities. It is unnecessary here to do more than draw attention to a few of the phenomena which it will be necessary to apply and extend in the development of the major thesis of this paper.

Where minor inlets are in free communication with the open ocean, as is the case with the majority of bays and gulfs indenting continental coast lines, there exist fully balanced faunal assemblages yielding direct analogies with those of the great bulk of fossiliferous beds of every age and in every part of the world. There are representatives of coral reefs, shell banks, sandy bottoms with included fossil shells, muddy sediments with indigenous and introduced organic remains, and so on, *ad infinitum*. Each and every case presents its individual problems for research.

In other instances, as in many estuaries and deltas, the normal marine conditions are so disturbed by the influx of fresh water and by the amount of muddy sediment carried in suspension by that water, that conditions are rendered intolerable for the majority of oceanic organisms of all kinds. Marine plankton is killed if it is driven into such waters. Nekton avoids the toxic environment to the best of its ability, and the bottom conditions are too foul and too variable to support an abundant and well balanced benthos. Such situations are notoriously poor hunting ground for the biologist. Where open-sea types manage to survive they are generally dwarfed and depauperized. Curiously enough the last types to desert such environments are usually the scavengers. Tolerant types of gastropods, annelids, vast armies of crabs, and other scavengers survive the variations in salinity and turbidity, and effectively deal with the considerable amounts of land-derived organic matter as well as with the remains of such marine organisms as may be killed by being forced into the toxic environment. In spite of their turbidity such waters are adequately aërated, and bacterial attack accounts for most of the organic matter

left by the scavengers. Here, again, the conditions do not favor considerable accumulation of protoplasmic products.

It is unnecessary to discuss all the permutations of varying factors which may be met with in minor basins of different type, such as enhanced salinity, abnormally high or abnormally low temperature, and so on. In the vast majority of instances, while sufficient to deplete or even inhibit organic colonization of the waters, such variations do not bring about a new set of conditions leading to the introduction, entombment, and preservation of large quantities of "foreign" organic matter in the sediments.

The case of the Black Sea is quite anomalous. Here is a very deep, almost completely landlocked basin, effectively cut off from the open ocean and even from the Mediterranean Sea. Its surface waters are normally aërated and illuminated, but there is a lack of deep disturbance of the waters owing to great depth and to the absence of tides and currents. At a depth of 200 meters there is a deficiency of oxygen, aërobic bacteria cease to live, and anaërobic bacteria flourish. While, then, there are more or less abundant plankton and nekton and a not inconsiderable influx of land-derived organic matter, there is a complete inhibition of bottom life. The deeper waters are rendered toxic by the action of sulphate-reducing bacteria which decompose sulphates with production of sulphuretted hydrogen and collateral precipitation of ferrous sulphide. The ferrous sulphide causes highly characteristic blackening of the deposited sediment, and the toxic environment entirely eliminates the benthos, including the scavengers. In these conditions much or all of the organic matter raining down from the superficial sunlit waters eventually reaches the bottom and is "pickled" there.

Analyses show the presence in the Black Sea muds of a relatively high proportion of organic matter (9, 20) and various investigators have seen in this fact a possible source for the formation of materials analogous with the black shales of some geological formations which are presumably the source rocks of much of the world's petroleum.

Van der Gracht (9) proposes the term euxinic facies (Pontus Euxinus = Black Sea) for deposits of this type. He suggests, explicitly abandoning the strict application of the Doctrine of Uniformity, that the present is not to be regarded as a thoroughly typical period in geological history, and that profound modification of conditions may be surmised if, as seems probable, there have been, in the past, eras of wide continental expansion and particularly of such climatic variation as to cause reduction or even disappearance of the polar ice caps. Such ice caps he regards as the chief cause of the downsinking of

polar waters, and their equatorward creep in the abysmal depths, thereby providing for the existing effective aëration of very deep oceanic waters. Arrest of the abysmal circulation would give rise to great extents of ocean bottom within which euxinic conditions would be developed, and in which, therefore, the accumulation of black muds with high organic content could take place.

Attractive as this theory undoubtedly is, it is necessary to establish that the deep oceanic circulation is controlled in the way suggested and that it is not a cosmic phenomenon as suggested (p. 1111); and also to take into account the many evidences of rapid alternation of shallow-water and even epicontinental sediments with many of the most extensive black-shale series of oil fields and other marine deposits in older geological formations.

There is another existing basin in which deposition of sediment and organic matter is taking place at the present time under conditions of complete abnormality. The basin is quantitatively insignificant in comparison with the bulk and distribution of any major terrestrial formation, and the conditions are so anomalous as to have been deliberately excluded from consideration by most investigators. This basin is a bay opening out of the Caspian Sea, known as Karabugas, described by Andrussow and others.

The Caspian Sea itself is entirely isolated from the ocean and its fauna and flora are therefore quite different from those of the ocean, and a direct comparison is impossible.

Karabugas is separated from the Caspian by a barrier which is pierced by a narrow strait. Owing to the aridity of the hinterland, the shallow waters of Karabugas suffer excessive evaporation, and are depleted thereby. As a result of this the level of the water is lowered, and a permanent inflow current from the Caspian is induced. Evaporation has proceeded to the point of saturation of the waters of the gulf, and salt is deposited in some places round its shores.

The waters of the Caspian Sea teem with fish and seals, typical nekton organisms animated by pronounced tropisms causing them actively to shun waters of uncomfortable salinity. As they are swept towards Karabugas by the inflow current they endeavor to escape, and the majority of individuals succeed in doing so. Nevertheless, vast numbers of fish and many seals, particularly young ones, are swept into the gulf. All are quickly blinded by the highly saline water, and the fish are killed in enormous numbers by the excessive salinity. Their bodies are cast up on the shores, *and resist decomposition for long periods*. This preservation is due partly to the total absence of aquatic scavengers, which can not exist in waters of such high salinity, and

partly to the pickling action of the brine. It is recorded that vast flocks of gulls and cormorants live on the dead fish, disdaining to eat anything but the eyes, as the supply of such delicacies is so inexhaustible.

A certain amount of oily material is derived from the pickled fish remains, and petroleum-like products are met with in some abundance. It would be rash, however, to claim that so anomalous an occurrence is an indication that all petroleum or even much of it is generated in this way.

Karabugas forms the basis, however, for the speculation that, at some times and at some places in the earth's history, there *may* have been developed somewhat analogous conditions on a scale sufficiently large and in environments sufficiently favorable to give rise to accumulations of sediments, rich in organic matter, and capable of explaining some of the earth's great petroleum deposits.

PHENOMENA OF BARRED BASINS

The writer therefore proposes to discuss the following questions.

1. Under what circumstances, if any, could major barred basins have been produced during the geological past?

2. What phenomena, other than those operating at the present day, could be anticipated in such basins?

3. To what results would such phenomena lead?

4. Are there any ancient geological formations the development of which can be explained more satisfactorily by such assumptions than by strict application of the Doctrine of Uniformity?

If crustal stability persists for a very protracted period, sub-aërial erosion reduces a land surface to the condition of a peneplain. This is not absolutely featureless, as is sometimes erroneously visualized, but possesses a subdued topography. Surface drainage on such a surface is exceedingly sluggish. Even at a very late stage of peneplanation low, but well defined ridges exist in positions largely or entirely controlled by the distribution of hard or resistant portions of the basement rocks of the region. The ridge pattern is therefore notably variable in different places according as the structure in the basement rocks is simple or complex.

Marine erosion, though less pronounced than sub-aërial erosion, is effective (Twenhofel, 23), and during a period of crustal stability extensive submarine planation tends to develop a platform continuing the slope of the peneplain surface beneath water level, probably with a slight wrinkle or ridge marking the actual shore line. Resistant bands may remain as submerged ridges.

Depression of such a maturely developed peneplain causes the

flooding of the former continental surface by epicontinental seas which are necessarily shallow and have gently shelving floors. In such circumstances it may be expected that there would be *basins* formed in the negative areas, more or less separated from one another by ridges of resistant rock material.

According to the depth and completeness of submergence of these positive features, we may recognize: (1) "banks," linear or irregular rises on the sea bottom, shallow in comparison with the adjacent negative areas, but nevertheless covered by moderately deep waters; (2) "bars," ridges covered by very shallow water for the most part, but possibly emerging above sea-level in places; (3) "barriers," ridges mostly above sea-level, but breached locally by channels which maintain a connection between the waters of the basin and those of the open sea.

On this classification, banks introduce important local variations in the environmental conditions, but do not prevent the full circulation of ocean currents. Banks and their associated basins may receive mechanical sediments of markedly different facies, the deposits on the banks being necessarily coarser in texture than those in the basins (Los Angeles region, 22). The influence of such differences in environment on the facies of the benthos is certain to be profound (Walther, 26; Twenhofel, 23), and may cause the development of strongly contrasted assemblages in closely contiguous areas. Even so, each assemblage is, *per se*, a balanced one.

Banks may affect profoundly the distribution of benthos, and to a minor extent that of nekton and plankton. Most bottom-living organisms are extremely sensitive to bathymetric control. The existence of a narrow, deep channel or of a submerged ridge of quite insignificant width may suffice to separate essentially different faunas in closely adjacent regions of the sea bottom and of equal depth.

Where a bank encloses a basin it is quite conceivable that the bottom of the basin, at any particular depth, may be colonized by an assemblage of benthos, completely balanced *intra se*, but lacking many of the forms occurring at equal depths on the outer slopes of the bank. While, as already stated, such differences may be due exclusively to bathymetrical considerations, it must not be overlooked that, owing to interference with the free action of deeper ocean currents, the waters within the basin may possess chemical and physical characters quite different from those of open waters in the vicinity.

The possibility of development of euxinic environment under these conditions is discussed elsewhere.

Bars and barriers have much in common and may be considered

together. By restricting more completely the play of ocean currents they have much more pronounced effects on the conditions of the enclosed basins than have "banks." These effects may amount to complete inhibitions of organic life or may be more partial in their results. The phenomena in such basins are considered in greater detail in the following paragraphs.

Such *fundamental* structures as these, which may be called structural basins, produced by the distribution of resistant ancestral rock structures, by no means exhaust the list of types which may function in the production of barred basins. Irregularities may be produced by warping and faulting, forming tectonic basins. In addition we must recognize ridges of accumulation of various types which may be equally effective in controlling the phenomena of deposition in the waters which they enclose.

Thus, in suitable environments, sediments and organic accumulations such as shell banks, coral reefs, or algal reefs, may so raise the levels of submerged banks as to convert them into bars, and thus render them much more effective as partitions between enclosed basins and open ocean.

Bars may be formed also by deposition of mechanically formed sediment in a variety of ways. Thus, along the eastern coast of the United States, bar and barrier development has reached spectacular dimensions. It is unnecessary here to do more than refer to the complete accounts of the phenomena available in many American geological publications.

There is perhaps, in the very perfection of development of the structures in this last case, a risk that implicit application of the limited Doctrine of Uniformity may cloud the issue and lead to the neglect of consideration of other possibilities in regard to bar formation on coasts. Thus, the eastern coast line of the United States is generally *convex* towards the Atlantic, and is swept by a powerful longshore current. Is it not possible to visualize the existence of a coast line strongly concave towards the ocean and not swept by a continuous longshore current? The writer has recently observed a case, on a very small scale admittedly, where such a method of bar formation appears to be suggested.

At Lake George, approximately 25 miles northeast of Canberra, there is a basin of internal drainage 50 miles long, which since the settlement of the country a little more than 100 years ago, has been occupied at long intervals by a shallow lake, but which is ordinarily almost dry. There is abundant evidence that in Pleistocene or early Recent time the climate of the region was much more humid than at

present, and that a large and permanent fresh-water lake existed here. The long axis of the lake, north and south, is parallel with the direction of the most powerful winds, which are southerly. It is suggested that, during exceptionally strong or persistent southerly winds the waters were driven toward the north, and there forced to bank up in the narrowing northern end of the lake. This process continued until sufficient "head" was developed to initiate a gravity stream flowing southwards along the bottom as an "undertow." This stream, transporting large amounts of sediment, encountered the general body of northward moving water, and at a point determined by local conditions a band of "dead water" was produced. Here were deposited the gravel and sand transported lakewards by the undertow, and there was developed a *transverse* gravel bar stretching completely across the former lake bed, at a point some miles south of the head of the valley, and now forming a striking gravel ridge.

Conceivably, similar structures on a much grander scale may have been formed, especially on very gently sloping shore lines, under sets of earth conditions different from those prevailing at the present time.

The formation of river bars is too well known to need more than mention. Again, however, it may be suggested that there is a distinct probability that not every variety of estuary possible is now represented amongst the earth's rivers.

There are possibilities that bars may be produced, in exceptional circumstances, by major landslides damming valleys, by extension of lateral deltas, by the accumulation of volcanic products, of glacial products, and in other ways. While it might be profitable to examine exhaustively all such possibilities, space does not permit it at this stage.

The probability that many of the types of bar here mentioned are not recognizable in existing geographical conditions is accepted as one of the necessary postulates of the theories now advanced.

The processes taking place within enclosed basins of the types previously mentioned necessarily vary considerably in different climatic and physiographic environments.

As already indicated (p. 1118), basins enclosed within "banks" do not differ essentially from open ocean, in so far as they are open to the action of tides and currents which tend to maintain their conditions in equilibrium with those of surrounding oceanic areas.

It is conceivable that basins of this type might be so situated that the equatorward creep of cold bottom waters could not surmount the obstacles imposed by the banks, and that other compensating factors might be absent, so that the enclosed waters *might* fail to be ade-

quately aërated. In such cases a euxinic facies could be developed, as visualized by van der Gracht. Unless, however, such isolated basins were close to the shore line, it is difficult to imagine how there could be brought about an oscillatory alternation with shallow-water or fresh-water conditions so commonly existing in the black shale deposits of the past, which are certainly to be regarded as the nearest analogs of the limited euxinic deposits of the present day. Alternation with *open-water* marine beds might be anticipated, but not with littoral deposits or fresh-water beds.

Basins which are cut off from the open ocean by bars or barriers are likely to develop much more abnormal conditions than do those in which the connection with the sea is more complete and permanent. While minor differences undoubtedly distinguish barred basins from those closed by barriers, it is sufficient for present purposes to consider the two types together.

Obviously the topography of the hinterland has a profound influence on the nature and texture of the mechanical sediments carried into the basins from the land surface. The nature and amount of the organic contributions from land sources is also influenced by the same factors. The writer believes, however, that climatic factors are to be looked upon as those which exercise a dominating control.

In humid regions barred basins function as lakes of various kinds. The access of meteoric water from the land surface by way of rivers is considerable. As precipitation preponderates over evaporation, a permanent outflow current is maintained through the openings in the barrier or over the low points of the bar as the case may be, and the salinity of the water is below that of sea water. In all such cases, then, regular and abundant entry of marine life is precluded. It is not impossible for strong or continuous onshore winds to introduce *episodically* some marine forms, and of these plankton and nekton forms are more probable than benthos. The possibility of occasional detachment of even benthos composed of sessile organisms by violent storms, and their introduction into closed basins, is sufficient to explain at least some of the anomalous occurrences of sea shells, even in pure fresh-water beds.

If the continental surface is in a stage of physiographic development not too far advanced, the topography of the hinterland is moderately accentuated, clastic material is abundant and coarse, and strongly dominant over organic contributions. The deposits forming in the basin under such conditions are those of normal lacustrine facies.

It is not unreasonable to suppose that, in some instances, con-

tinued negative epeirogenic movement may not seriously disturb the balance of conditions. Openings in bars and barriers may be preserved with little alteration by the deposition of clastic sediment of the river-bar type. In this way there may accumulate considerable amounts of lacustrine sediments, too thick to be explained as the deposits of an ordinary lake, laid down during a single geographic cycle in a basin of determinate dimensions from the outset.

While this process is going on at the present time in innumerable *small* barred basins, it does not seem possible to point to similar phenomena on a major scale, comparable, for instance, with those which produced the Triassic and Jurassic fresh-water sediments of eastern Australia with which the writer is particularly familiar. It is believed to be a legitimate extension of the Doctrine of Uniformity to suggest that, at various times in the geological past, much more extensive basins of this type may have existed during periods of extensive peneplanation and epeirogenic movement, than can be found during the present, possibly abnormal, era, which is one of orogenic activity as a whole.

If, as may be postulated, there were periods of very extensive and perfect peneplanation, like that which appears to have affected Australia in Middle Tertiary time, and the land surface were submerged, with consequent development of extensive barred basins, a quite different set of conditions would be imposed. As before, constant outflow in such circumstances is kept up through the bar or barrier openings, the water is maintained in a fresh (or at least brackish) condition, and marine life is excluded.

Since, however, stream gradients are low and currents are sluggish, only fine detritus, and relatively little of that, is introduced into the depressions, and, in suitable climatic conditions, luxuriant growth of vegetation in and around the basins is favored. Here we have just those conditions which seem to be demanded, on the basis of the work of Potonié, for the development of coal deposits. Even the formation of allochthonous coal seams can be explained readily in these circumstances. All that is required is abundance of suitable vegetation growing under conditions favoring its indrift into the basin. The astonishingly low ash content of some allochthonous coals, for instance the brown coals of Gippsland, Victoria, Australia, indicates the absence of any appreciable amount of clastic sediment. Such "filtration" of water possessing sufficient movement to float in enormous amounts of vegetable matter, may be accounted for either by the advanced peneplanation of the hinterland, or by the existence of "preliminary settling tanks" acting in the same way as the "catch-

all" dams used in connection with rain-conservation earth tanks in the drier parts of Australia to promote the settlement of the coarser debris carried by flood waters, and to prevent the rapid silting of the main storage tanks thereby.

Widespread shallow basins on a *peneplain surface* seem to provide ideal *loci* for the continued growth of peaty vegetation suitable for the formation of coal seams of allochthonous type similar to those visualized by Potonié. There need be no limitations in size under the conditions postulated, and coal fields of continental extension are possible. Such extensive peneplanation certainly occurs; the Middle Tertiary peneplanation of Australia, for instance (30), appears to have been continent-wide.

In the deeper and more isolated portions of such basins the local development of anaërobic conditions is readily conceivable. In such circumstances the accumulated vegetable matter may have tended to produce bogheads, torbanite, kerosene shale, *et cetera*. The distribution and association of kerosene shales in the coal measures of New South Wales is quite compatible with such an explanation.

Under somewhat different climatic conditions, where the growth of specially luxuriant vegetation is not favored, it is possible for the basins to have contained a much higher proportion of animal matter. It is likely that excess of humic acids, such as would be developed under the coal-forming conditions previously outlined, might be expected to reduce very materially the habitability of the waters for animal life. In purer waters, however, such life might flourish luxuriantly. If the waters were sufficiently well aërated to cause oxidation of the readily decomposable animal matter, the only traces left would be fossils of the hard parts (calcareous and siliceous tests, chitinous skeletons, *et cetera* of fresh-water fauna), and the clastic sediments would be essentially lacustrine in character. If conditions, however, were such as to cause inadequate aëration, much of the protoplasmic matter of animal origin would be preserved after entombment. Under such circumstances we might expect oil shales of the Green River (Montana) type rather than coal. Though the problem has not been adequately studied, it appears that such conditions of low aëration would be most favored by the relative stagnation of the water subsequent to the perfection of peneplanation postulated, a condition which would not occur in lacustrine basins fed and drained by effective river systems such as must be developed when the topography is at all strongly accentuated.

Here again, slow and long continued epeirogenic movement should not interfere seriously with the maintenance for long periods of

essentially similar conditions, so that notable thicknesses of sediment could accumulate as a result of isostatic adjustment.

Other interesting results, apparently corroborated by facts of observation, may be deduced from the same speculation.

By hypothesis, the relief of the land is extremely low, and the land surface passes almost insensibly under the neighboring sea, whose bottom also is very gently sloping (see p. 1117). In such circumstances it will require only insignificant epeirogenic movement to cause a very considerable marine incursion or retreat. *Quantitatively* this assumption is easier to admit than are the recurrences of major earth movements necessitated to account more conventionally for the marine and fresh-water intercalations which are so commonly encountered amongst the geological formations of the past. The general absence of major base-levelled surfaces at the present day has certainly blinded most geologists to the possibility of much more extensive development of such features in the past, and has caused them largely to neglect the consequences which must necessarily follow such extensive peneplanation.

Aridity of climate is not a marked feature of present-day conditions, though there appears to be world-wide evidence that, in spite of marked positive and negative climatic oscillations, there is now a general tendency towards increasing aridity. This is definitely the case throughout Australia. The evidences of considerable aridity in some parts of the Ordovician, Devonian, Permian, Triassic, and Oligocene seem to be well marked, and it is probable that exceptionally arid periods may have been at least as common as glacial periods, for which Coleman has produced such conclusive evidence.

While it is probable that there are several causes for the development of redness of color in sedimentary series, the writer is much inclined to champion the discredited cause of "Red-beds" as criteria of general aridity, particularly where such beds are associated with green and purple beds and with definite evidences of salinity in the form of gypsum and salt deposits.

High aridity of climate associated with the existence of barred basins brings about the development of conditions which are of very great importance, and which, in the opinion of the writer, may well be the major factors in determining the environmental control of many important deposits.

Complete aridity of climate inhibits river drainage on a continental surface. At most, episodic torrential flooding takes place, and occasional deposits of coarse and ill-assorted detritus may be swept

along and laid down in negative areas. Chemical weathering is favored, and case-hardening of superficial formations may result (30, 32). Wind action is an important factor in denudation (25) and its products tend to collect in the lowest portions of the area. It is the writer's belief that, while redness is not ubiquitous, red coloration is rather characteristic of such deposits. Any reducing action causes reduction of the iron to the ferrous state, with consequent development of bright greenish tints, so that an admixture of reds and greens in the coloration of the sediments *may* be indicative of desert conditions of deposition.

If the topography is rugged, sub-aërial, fan-shaped, torrential deposits may be strongly developed in the basins. If, on the other hand, the hinterland is effectively base-levelled, the land-derived deposits in the basins will be fine-textured, and may be entirely subordinate to those produced by direct chemical precipitation.

Barred basins of considerable areas are likely to be developed by submergence of a well developed peneplain. In such a climatic environment evaporation is enormous. Under these circumstances the development of a strong and *permanent* inflow current through the openings in the barrier or over the slightly submerged crest of the bar, as the case may be, is inevitable. If it were not for this *maintained* connection with the sea, the history of such a basin would be short. All the contained water in a closed basin would be evaporated rapidly and the dissolved salts would be deposited in regular order. A salt deposit would be formed, and might be preserved by burial beneath wind-borne and water-borne detritus. The whole of the soluble matter originally present in the waters of the enclosed basin would be concentrated in the deepest hollows into which the shrinking volume of the solution would have gradually withdrawn, and would not, in general, be distributed over the whole of the basin. In any case, the *quantity* of saline material so deposited would be strictly limited to that dissolved in the original water, and it is inconceivable that any of the major primary salt deposits of the world could have developed their known tonnages in this way, during a single cycle of evaporation.

By maintenance of connection with the open ocean through bar channels the volume of the solution in the basin is reduced only to the point of equilibrium between evaporation and inflow. The concentration of the solution is enormously protracted owing to constant accession of normal sea water. Nevertheless, concentration is gradually and uniformly increased, and may ultimately attain saturation for the less soluble substances. Deposition then commences, and

continues uniformly so long as the equilibrium of conditions is maintained. This is the time-honored theory of Ochsenius (5, 14, 15), shorn of some of its bizarre excrescences.

The order of succession of minerals deposited is that determined by Usiglio and van't Hoff in their experimental researches on the evaporation of sea water, with the additional factor of constant accession of fresh solution.

The first precipitation consists of the small quantities of iron and aluminum hydroxides dissolved in the ocean water, together with the likewise small amounts of calcium carbonate and silica. Owing to constant replenishment, however, the quantity of these substances actually deposited is the *integral* of the content of the sea water taken over long periods, and thus the volume of such precipitates may be very considerable indeed. It must be remembered also that the results of profound chemical weathering of an arid *peneplain* produce iron, aluminum and calcium salts and soluble silica in considerable amounts and it is these substances which build up that case-hardened crust to which, in Australia, the writer has applied the name of "duricrust" (30, 32). The contributions of soluble matter introduced by the relatively insignificant drainage from the base-levelled continental surface therefore reinforce the direct results of precipitation from sea water, and it is little to be wondered at that very considerable thicknesses of fine-textured sediments dominantly aluminous, ferruginous, and calcareous, with an admixture of hydrated silica, should be deposited under such circumstances.

This phase of the process has been somewhat emphasized because it is believed that deposits of the kind mentioned are somewhat extensively distributed. Through failure to appreciate fully the possibility of development in the manner here described, such formations are usually referred to merely as claystones, and their possible historical significance is at least minimized in most geological literature.

Should equilibrium of conditions be maintained sufficiently long, a point of concentration is eventually reached when gypsum begins to be precipitated. If the temperatures of the water are sufficiently high, the calcium sulphate is precipitated as anhydrite. It has been shown that temperatures adequate for this precipitation can be produced by absorption of solar heat in brines, so that the occurrence of primary anhydrite in brine basins in arid climates and in tropical and subtropical latitudes is not surprising.

Further concentration leads to deposition of sodium chloride. As the inflow current is functioning throughout the whole of the process, it is not surprising that rock salt deposits presumably formed by the

processes here described, should show banding with gypsum or anhydrite.

The magnesium and potassium salts which constitute the most valuable products of a few major salt deposits are so intensely hygroscopic that their crystallization and *preservation* call for desiccation of a most extreme type. This is probably a reason why such valuable deposits are so few in number, and so limited in extent. For deposition of such hygroscopic salts it seems necessary to assume that, in the last stages of the process, the basins became isolated completely from the ocean, and that the inflow current ceased to function, while the climate increased in aridity.

Throughout the whole of the process above outlined, land-derived materials, chiefly wind-blown, were added more or less continuously, but chiefly episodically. Such red dusts, interbedded with the chemical precipitates, assist in sealing and preserving the soluble materials from subsequent solution.

It is necessary now to consider some of the implications of such a set of conditions. By hypothesis a connection with the open sea is maintained through the bar openings, and there is a constant inflow current of the type observed on a small scale at Karabugas. The plankton abounding in the *surface* waters of the ocean is swept in through this opening in vast quantities. Except in the very earliest stages of the history of the basin, its waters are necessarily inhospitable to such oceanic forms of life, and the conditions become increasingly unfavorable as concentration proceeds. From the outset, then, the introduced plankton is destroyed *in toto*. While some of the plankton, such as foraminifera, radiolaria, diatoms, some crustacea with chitinous carapaces, and a few types of organism attached to seaweed and other floating material, have hard parts capable of being preserved as fossils, the bulk of the organisms, both plants and animals, are gelatinous and devoid of hard skeletons, and are incapable of leaving any record of their presence. The strictest disciple of the Doctrine of Uniformity would not deny the possibility of existence and destruction of enormous numbers of such soft plankton organisms even in ancient geological eras.

In the very early stages of existence of the basin, it is conceivable that normal aëration of the water might exist. Even in such early stages, however, it is far more probable that there is a definite oxygen deficiency, since the enclosed nature of the basin excludes tidal action and normal ocean currents. In the immediate neighbourhood of the bar openings, aëration may continue for a considerable period, but, even here, the bulk of the oxygen is rapidly absorbed by the dead

protoplasm. It is obvious then, that, in general, anaërobic conditions must prevail within the basin. As saline concentration proceeds and the density of the solution increases, normal convectional currents become inoperative, the heavier solutions sinking to the bottom and remaining there, the surface layers, themselves very saline, being somewhat diluted by the inflow water and by meteoric waters. Even wave action is unable to supply oxygen to the deeper layers. Under these conditions a typical euxinic environment develops.

Benthos is entirely eliminated, and nekton organisms are introduced only casually. As soon as organic matter, even that which under normal conditions is extremely unstable, sinks below the actual surface of the water, it enters an anaërobic environment. Chemical modification goes on, assisted by the action of anaërobic micro-organisms, but complete decomposition into water and gases does not occur. The modified organic matter accompanied by more or less detrital mineral matter, chiefly fine-grained because largely wind-blown, sinks to a muddy bottom under conditions favoring entombment.

Many of the larval and immature stages of organisms which in their adult condition are sessile or possessed of limited powers of locomotion are free-swimming. Such types may be drawn into the basin and killed by the toxicity of the waters. It is noteworthy that Walther (24), one of the most strenuous opponents of the "bar theory" of Ochsenius, records as fossils in saline deposits just such types as these.

It is obvious that, while forms such as most radiolaria and foraminifera and certain diatoms are exclusively marine in normal habitat, their presence in vast numbers in certain formations may constitute the most positive proof that the formations in question were *not* normal marine sediments. It is only when the pelagic forms mentioned are associated with a *balanced assemblage* of benthos indigenous to deep-sea conditions that true oceanic conditions of deposition can be deduced.

The waters of the barred basin are unsuited for the maintenance of any but a highly specialized assemblage of indigenous organisms even under the most favorable conditions. High salinity (carrying with it usually high temperature), lack of oxygen, and other factors produce a toxicity which generally destroys *all* aquatic life in such situations. There is thus an absence of bottom-living scavengers, and sunken organic matter is preserved.

The introduction of planktonic life may well be uniform and continuous under some conditions, so that the deposits in the barred basins may show an even distribution of fossil types throughout notable thicknesses.

On the other hand, accession may be markedly episodic in character. Violent onshore winds tend to bank up the water on the lee shore, particularly where that shore line is very gently shelving, as is the case when base-levelling is far advanced. The banking up is caused probably even more generally by long continued onshore winds which do not attain storm strength.

During the continuance of such conditions the level of the water over bars and barriers is raised, ingress of pelagic forms is facilitated, and, temporarily at least, the *surface* waters of the basin may become habitable. If concentration has progressed appreciably, such sea floods will spread over the denser, *still* waters of the deeper levels, and will not affect basin conditions for any considerable period of time.

Such invasions may occur only at very long and infrequent intervals, giving rise to occasional zones in the sedimentary deposits literally teeming with fossils of one species or one general type, and separated by unfossiliferous or meagerly fossiliferous beds of considerable thickness. This may account for such phenomena as the fish fossils of the Kupferschiefer, where the attitudes of the individuals suggests that they were destroyed by poisoning. An Australian instance described on page 1135 by the writer is the occurrence of a bed crowded with the cephalopod *Paralegoceras* (wrongly identified originally as *Gastrioceras*) met with in the otherwise barren beds of the Irwin River formation in Western Australia. The phenomena of many of the graptolite-bearing formations suggest a similar *episodic* invasion of basins by plankton organisms.

It must be remembered also that planktonic invasions sometimes occur in existing seas with little apparent reason. The periodic appearance on the bathing beaches of Sydney of argosies of *Physalia* causes the complete rout of tens of thousands of surf bathers from time to time. The writer can remember an occasion (about 1886) when the beaches of the east coast of Australia were deeply covered for hundreds of miles by veritable *embankments* of *Solen* valves.

It has been suggested that the episodic distribution of such fossils as graptolites in some formations is explainable by tidal inundations of shelving shore lines. This appears unlikely to the writer. Tidal phenomena are strictly periodic, and are essentially of short period. The abnormally high tides at Broome on the northwest coast of Australia occur twice annually, in March and September. Ordinarily, tidal effects have a periodicity of only one lunar month. Even annual recurrences would be, to all intents, continuous phenomena in any series of deposits on a geological scale, while the episodic and catastrophic destructions of plankton in the cases referred to are evidently separated by very long intervals, even geologically considered.

The phenomena described visualize ideally perfect development of the conditions of a barred basin. There are many possible modifications and imperfections. In such cases the results will be correspondingly partial. An inefficient bar connotes a degree of interference with normal marine conditions without complete exclusion of marine life. The hardier forms of organisms are capable of survival, though in diminished numbers and generally in depauperized condition. The more sensitive organisms are excluded. As pointed out, many of the scavenger types are relatively tolerant of unfavorable conditions. In such cases the deposits of the basin correspond with those of many bays; assemblages are ill-balanced but organic matter is eaten by scavengers or decomposed. In such imperfectly closed basins aëration is intermediate in efficiency, and various stages between complete oxidation of organic matter and development of euxinic deposits may be expected.

The association of land-derived fossils with barred-basin deposits need cause no surprise. In even very arid regions there is usually a characteristic erymophyllous flora of notable amount scantily clothing the land surface, and supporting a fauna specially adapted to withstand the rigors of the climate. Remains are introduced into the basins by occasional floods. Climates are subject to marked fluctuations throughout periods covered by geological intervals of time, and, even without any marked change in the level or relief of the country, there may be oscillations between fresh-water and saliferous deposits in the basins. The association of leaves and stems as fossils in foraminiferal beds, as described in the Neogene rocks of Sumatra (12), and as known to the writer in the uppermost Permian beds in New South Wales, finds ready explanation in this way without invoking wholesale changes of land and sea.

In barred basins then, are: (1) a supply of organic matter, derived from *continuous* plankton inflow, which is quantitatively adequate to supply the most exorbitant demands for the raw materials of petroleum genesis; (2) conditions for preservation of this material from the complete decomposition which takes place normally on the bottom of the open sea; and (3) conditions for the accumulation of sufficient mineral detritus, without the action of aërating currents, to account for effective entombment and preservation.

It is probable that increased salinity alone might be effective in preserving organic matter when a somewhat advanced stage of concentration of the brine has been reached. It is probable, however, that such high concentration is attained only in comparatively few instances. Even slightly increased salinity would be sufficient to

account for all the observed phenomena. In still fewer cases has the process gone on to the actual precipitation of salt and gypsum.

Under some such circumstances as those outlined is found adequate explanation for many of the phenomena associated with oil fields. It is definitely *not* claimed that all source rocks have been produced in this way. All that is desired is to indicate one method, largely neglected in the past, whereby such rocks may have been formed. Possibly the majority of petroleum deposits have had a different mode of origin.

In this connection it is worthy of consideration that petroleum consists of hydrocarbon molecules of relatively simple types of structure. Their derivation from the highly complex molecules of protoplasm is thus a *degeneration*, and such a breaking down may occur in a variety of ways. The synthesis of complex molecules from simple ones is usually a much more difficult problem than is the formation of simple molecules from complex ones, and the most complex molecules of all require the alchemy of life for their production. If this be true, it is to be anticipated that oil may be derived from complex organic molecules by a variety of different reactions, and that purely laboratory methods may be misleading.

Deposition in barred basins in arid climates, in accordance with the processes already described, gives a satisfactory explanation not only for the accumulation and preservation of an adequate quantity of organic matter for the generation of the vast amounts of petroleum actually observed in nature, but accounts almost equally well for some of the collateral phenomena of oil fields, such as association with black shales, the composition of typical oil-field waters, and intercalations of non-marine facies. It must be emphasized by repetition that, while the ultimate result of desiccation, if carried to completion, must be the production of deposits of rock salt and gypsum, such as are not infrequently encountered in association with petroleum, the introduction and preservation of the plankton commences at a much earlier stage of the cycle, and may lead to adequate accumulation of organic matter long before there is any trace of saline precipitation.

The existence of anaërobic conditions leads to the elimination of aërobic bacteria, and the development in their place of anaërobic micro-organisms, including sulphate-reducing bacteria. With the as yet debatable question as to how far such bacteria are directly responsible for the conversion of organic matter to petroleum it is not proposed to deal here, though the writer is greatly impressed by the demonstration of the existence, in oil-bearing formations as old as Ordovician, of anaërobic bacteria differing from modern types *only*

in such characteristics as a temperature toleration which can easily be explained as an evolutionary adaptation to environmental conditions (4, 7, 19, 21).

Certain it is that sulphate-reducing bacteria are capable of producing euxinic conditions resulting in the removal of sulphates from normal sea water, generation of hydrogen sulphide, and precipitation of black ferrous sulphate which is a known cause of the dark coloration of many of the black shales of existing oil fields and other formations.

Further, if we take into consideration the phenomena of concentration already postulated, we have a reasonable explanation also of the nature of many oil-field waters. Not only does the ubiquitous association of petroleum with common salt become a genetic one, but we have a reasonable cause provided for the common association also of bromides and iodides which have been detected in many oil-field waters (20, 27). This, combined with the paucity of sulphates and the presence of sulphuretted hydrogen in such waters, is a very striking fact.

The duration of barred conditions is notably variable. There is no reason why a structural or tectonic bar, formed of ancestral resistant rock material or by earth movement, may not persist for a very long time. In an area subject to epeirogenic movement, the weaker portions forming the basin may continue to subside under conditions of slow warping, leaving the stronger portions forming the structural or tectonic bar relatively unaffected. In such a case great thicknesses of sediment may accumulate within the closed basin.

In other instances the bar or barrier may be subject to intermittent or periodic failures of various kinds. Thus, if earth movement is relatively rhythmic, there may be alternations of floodings and desiccations. In other cases bars of accumulation may be destroyed by exceptional storms or other catastrophic phenomena, leaving the basin open to the sea for longer or shorter periods during which normal marine life with balanced assemblages of organisms may colonize the basin. Rebuilding of the bar by sedimentation may again induce euxinic conditions, with recurrent deposition of black shales containing unbalanced faunas.

It has been customary in the past to explain all marked changes of sedimentary or paleontological facies by major earth movement. As pointed out by Twenhofel (23), this is by no means necessary in every instance. If the suggestion of the existence of barred basins prove acceptable, many of these changes need nothing more than a temporary failure of a weak sedimentary structure to explain them. If, in addition, it be postulated that many deposits are laid down on an intensely

base-levelled surface of very gentle inclination and low relief, profound changes of sedimentary environment can follow a very slight alteration of the relative levels of land and sea.

A somewhat common case would appear to be the rhythmic depression of a gently shelving shore line. During the active periods there are deposited conformably a series of normal, fossiliferous marine sediments. During the periods of still stand, conditions favor the development of offshore bars, and a succession of euxinic deposits occurs within a limited geographic range, but extending through a considerable time interval. The accounts given by Hövig of the oil horizons in Eastern Sumatra (12), extending apparently from Lower Miocene to Upper Pliocene southwest and northeast *may* be attributable to some such cause.

If there occurs an alternation between sediments with abundant planktonic fossils, especially if the shales are dark in color, and ordinary marine deposits of shallow-water facies, and still more if freshwater deposits enter into the succession, the difficulty of interpreting the former as *pelagic* deposits involves oscillations of sea-level or major earth movements which are quite inconceivable. The explanation of the planktonic deposits as those of barred basins close to continental shore lines removes this difficulty, and calls for only minor causes to produce profound changes of facies.

GEOLOGICAL EVIDENCE OF BARRED BASINS

In inquiring whether, and if so, where, evidences of deposition in barred basins may be sought amongst the geological formations of the past, it is necessary to bear in mind several pertinent facts. Firstly, bars and barriers of the type mentioned possess areas small in comparison with those of the basins which they enclose, so that they may be easily overlooked even if they crop out. Secondly, they may in the majority of instances, have been buried beneath more recent formations. Since drilling for oil *may* be confined entirely to the basin deposits, the existence of the bars may not become apparent. Thirdly, many types of bars are weak and temporary structures, subject to contemporaneous erosion, and capable of entire removal in this way, leaving no direct trace of their former presence. Fourthly, and probably principally, the conception of bar formation and of the phenomena associated therewith has not entered the minds of field geologists. Even the most conscientious investigator is influenced by his point of view. He observes and records fully those phenomena which bear upon the working hypothesis with which he is dealing, and overlooks or neglects facts which he regards as trivial or irrelevant.

The writer has made a hurried search through the meager literature available in Canberra, and has been astonished that so many descriptions of oil fields and other geological structures, examined and recorded with no idea of application of the theories here advanced, can be explained much more completely and logically by the application of these principles than by any other.

In the first place, brief accounts will be given of deposits personally examined by the writer which appear to present characteristics best explainable as sediments in barred basins; though, at the time the field work was done, there was no suggestion of this kind influencing the mind of the observer.

In the course of a single hurried visit in 1930, a traverse was made of the Carlsbad area of New Mexico. At the time, the writer was impressed by the apparent reef-like distribution of the limestones, reminiscent of the existing atolls of the Pacific with which he was familiar. Later, considerations of the implications of the barred-basin theory suggested that the distribution of the red-beds and saline deposits of this region in relation to the limestones might conform with the phenomena of such a basin. The suggestion is commended to those who are carrying out investigations in this interesting and perhaps critical area.

In the Irwin River district of Western Australia (31) an anomalous series of Permo-Carboniferous formations appears to conform closely with the requirements of the barred-basin hypothesis, though no bar can be pointed out at this distance of time and space. It was not suspected during the progress of the field work.

An important glacial series resting on pre-Cambrian bedrock is followed by a considerable thickness of buff calcareous claystones and shales, with here and there more ferruginous bands. Concretions are conspicuously developed on several horizons, and cone-in-cone structure recurs in many of the calcareous beds. As already noted, there is a possibility that such features *may* be connected with abnormal processes of deposition.

In the light of later considerations it is thought that this series of sediments represents fine detrital material deposited under arid conditions in a closed or nearly closed basin, in which the water, originally sea water, had been considerably concentrated. The concentration had not, as yet, reached the point of precipitation of gypsum; but iron, alumina, and lime were being deposited from solution. The only megascopic fossil known to the writer in this stage, with the exception of those of the *Paralegoceras* bed, is a single dwarf specimen of *Keenia* near its base.

At one point there is a bed of orange-colored ocherous claystone only a few inches thick, literally crowded with remains of *Paralegoceras* preserved in siderite. If, as seems probable, *Paralegoceras* may be regarded as a pelagic floating form, this horizon represents an episodic invasion of the basin either as a result of a phenomenally severe onshore storm, or as a result of a temporary breakdown of the bar. Not only did the floating shoals of the cephalopod invade the basin, and perish immediately in tens of thousands in its saline waters, but fresh accessions of iron and alumina were introduced with the influx of sea water, and temporarily darkened the color of the sediment in process of deposition.

The buff beds are followed by a thick series of dark olive-green shales which are now regarded as probably euxinic in facies. They contain sporadic, depauperized marine fossils, and much finely disseminated pyrite, but have not been examined for foraminifera. The oxidation products of the pyrite, reacting with the calcium carbonate of the deposit, have produced abundant selenite. This was formerly regarded as evidence of primary gypsum, but is probably more correctly interpreted as a secondary product of euxinic deposits.

Above the olive shales there is a zone, a score or two feet thick, crowded with a varied, well balanced and beautifully preserved assemblage of marine fossils. This points to a somewhat prolonged episode of open-water connection with the ocean, possibly through subsidence sufficient to submerge the crest of the bar somewhat extensively, or possibly through catastrophic demolition of the bar.

Reversion to closed-basin conditions follows. The overlying sandy beds are red and highly saliferous, though there is no evidence of precipitation of either gypsum or salt.

That continental land was not far distant is indicated by the succession of a few hundred feet of fresh-water beds with thin seams of poor coal.

These are followed by an "upper Marine" series in which fossils are scarce. The most common are depauperized examples of *Aviculopecten*. Since this form, by analogy with the modern *Pecten*, probably possessed limited powers of independent locomotion, it is conceivable that imperfectly barred-basin conditions prevailed during the upper Marine stage. Throughout the entire series there is evidence of refrigeration. On several horizons tillites are developed, and ice-dumped blocks are met with sporadically throughout the entire succession. This refrigeration might be considered the cause of the depauperization and scantiness of the fauna were it not for the fact that, at the Wooramel River, 200 miles north of the Irwin, contemporaneous for-

mations contain a much more abundant and much better balanced fauna than those considered here, but exhibit equally strong signs of glaciation.

It is not possible, at present, to determine the site of the bar or barrier. On the east and west the Permo-Carboniferous basin is bounded by heavy faults. The sediments of this age have been entirely stripped from the eastern areas, and deeply buried beneath Jurassic beds on the west. On the south there is a basement of Proterozoic and Archeozoic formations on which rest the basal tillites. There may have been a structural bar in this direction. Toward the north the Permo-Carboniferous rocks disappear beneath more recent formations for a considerable distance. Where they outcrop again at Eradu they are represented only by a fresh-water facies, marine types being absent. This suggests that a bar, if it existed, may have been situated south or west of the marine basin.

Within the admittedly limited range of the writer's study of the literature there is one outstanding case in which the existence of fossil bars has not only been established, but in which the individual bars have been thoroughly delineated by the results of drilling for oil. This is the example of the Bartlesville and Burbank "shoestring" oil sands of Kansas and Oklahoma. The evidence adduced by Bass (*2*, *3*) in his two papers is so clear that the writer has no hesitation in acclaiming the shoestring sands as a case of development of fossil bars, analogous with one type of those postulated in the present paper. In this instance the structures are sand bars, of minor dimensions, but of economic importance by reason of their oil contents. As shown by Bass they are closely analogous in all respects with the sand bars of the existing Atlantic coast line of the United States, resulting directly from coastal sand drift.

In this case it is the bars themselves which have been studied, and not the deposits of the barred basins enclosed by them. The writer has not the opportunity for pursuing this problem, but it is one which can be recommended to the attention of those who possess facilities for doing so. If sand bars can serve as oil reservoirs in certain cases, and if, as now suggested, the euxinic deposits within such basins may function as source rocks of petroleum, a close study of bar and basin conditions may well point the way for future prospecting operations in suitable environments.

An instance in which application of the principles of the barred basin may be applied with advantage to a region which has been excellently described by a highly competent observer whose ideas have not been influenced in any way by considerations of such a pos-

sible environment is the account by Hedberg (11) of Cretaceous limestones as petroleum source beds in Venezuela.

Hedberg divides the Cretaceous limestones into an upper series, the Congollo limestones, and a lower series, the La Luna limestones. The facies of these two types are almost diametrically opposed.

The La Luna limestones are dark-colored, thinly laminated, and highly carbonaceous beds. It is noteworthy that concretionary structure is common and present on a large scale. As already noted, this *may* be found to be diagnostic of barred-basin environment. Seams and nodules of black chert are also present.

Macroscopic fossils are extremely rare. Fish scales (nekton remains) occur in great profusion locally. The fossils are almost exclusively small pelagic foraminifera which are imbedded in "dark carbonaceous and bituminous matter" and the rock is almost uniformly petroliferous. Little sand impurity is present.

The Congollo limestone is a typical light-colored marine limestone with a rich and well balanced fauna and flora. There are considerable quantities of round elongated pellets probably representing the excrement of bottom-living invertebrates, testifying to the efficiency of bottom-living scavengers. The presence of such organisms may account for the difference in the amounts of organic matter present in the two limestone series. In the Congollo limestone the bitumen is obviously introduced and not indigenous material, and occupies only cracks and crevices in the rock.

Hedberg says:

> Life in La Luna seas seems to have been almost exclusively planktonic. During La Luna time the bottom waters evidently developed a "toxicity" because of the lack of circulation, due perhaps to depth, *perhaps to physiography of the ocean floor* [italics, W.G.W.], which rendered them almost uninhabitable by marine benthonic life. Remains of the abundant plankton at the surface accumulated undisturbed by the action of the bottom-living scavengers that must have existed in the Congollo sea. Moreover, this toxicity and the lack of oxygen probably prevented rapid bacterial decay and permitted partial preservation of the soft organic matter of the pelagic forms which settled to the bottom.

This account, which did not come under the writer's notice until after the first draft of the barred-basin theory had been prepared, could scarcely have been better adapted to the requirements of that theory had it been specially prepared for the purpose.

At the top of the La Luna stage there are numerous intercalations of limestone closely resembling those of the Congollo type; and in the bottom part of the Congollo others of the La Luna type. Hence there

must have been a period of delicately poised equilibrium during which oscillations of conditions were frequent.

Hedberg states:

> The Congollo and La Luna limestone types obviously represent two very different facies of sedimentation. It has been widely believed that the change from Congollo to La Luna deposition marked a change from deep-water to near-shore or shallow-water environment.

Now a *gradual* change from deep-water to shallow-water conditions should have been marked by a *progressive* and continuous change of facies. A *sudden* change must have been due to major earth movement which should certainly have manifested itself in some kind of disconformity. *Oscillatory* change from deep-water and open-sea to shallow-water and coast-line conditions imposes too great a strain on credulity. Can not the difficulty be met most simply by visualizing an intermediate period during which bar disintegration was in progress? The bar functioned for a time, producing La Luna conditions, sometimes it was breached, producing Congollo conditions, until, finally, it was permanently demolished, and the shallow open Congollo sea covered the area.

The writer believes that, in this case, as in others to be discussed later, the cause determining blackness and fine texture of sediments and inclusion in them of plankton remains has been erroneously attributed to *deep pelagic conditions* rather than to oxygen deficiency and tranquility which are explainable quite satisfactorily on the bar hypothesis.

Hedberg gives no indication of the existence of a bar. This could scarcely be expected under the circumstances, as the research was carried out with other conceptions in mind, and with definite economic objects, namely the location of oil prospects.

A further examination of the area, particularly in its peripheral portions, might bring to light the evidence of a bar or barrier. On the other hand, such evidence might easily be obscured by later formations or entirely removed by erosion.

Adams (1) describes the structure of the oil reservoirs of Yates pool, Pecos County, Texas, and this description, too, appears to provide reasonable suggestion of the development and functional activity of bars or reef structures competent to cause the formation of oil source beds by the processes here described.

The actual reservoir rock is regarded as a limestone reef rendered porous by leaching connected with contemporaneous erosion. This action is seen in the exposed "islets" of an existing coral atoll. Adams

also refers definitely to the possibility of development of a "sand bar" along the edge of the field.

He suggests that the source rocks were formed in local deeper basins from what he calls "benthonic soup." It is now suggested that he is in error in straining credulity by accounting for the absence of scavenging organisms in the "soup bowls" on the assumption of temperatures sufficiently low to "place an effective check upon the processes of decomposition and the activities of deep water scavengers." The same results can be explained by relatively high temperature and aridity, producing high salinity, and by inefficient aëration owing to tranquillity of the water in an almost closed basin.

Closely associated with the oil pool are beds of anhydrite, while in the immediate vicinity are red beds which may be interpreted as indicating both aridity of climate and moderately high temperatures. The paucity of fossils mentioned by Adams is in keeping with the requirements of the bar theory. Acceptance of this theory appears to demand fewer and simpler assumptions than those made by the author of the paper to account for the anomalous association of geological formations involved.

One would naturally seek for evidences of application of the barred-basin theory in Southern California, since no oil-bearing region has received such intensive study based on such complete surface and subsurface data. In their latest monograph Reed and Hollister (17) describe the evolution of the paleogeography and stratigraphy of the region very fully.

The fact that the diastrophic history of the region is dominated by long periods of epeirogenic calm, with consequent peneplanation of the continental surfaces, alternating with short periods of intense diastrophism (Reed and Hollister, p. 1596), accounts for the development of basin conditions on an extensive scale. Though the authors of the monograph have portrayed this history admirably, it is obvious that they have not viewed the data with any thought in mind of their application to the theory of the barred basin. Had they done so it is not unlikely that their descriptions would have provided conclusive proof of the action of such processes in place of mere suggestions more or less clearly deducible from the context in many places.

It would require a much more detailed knowledge of local conditions than the writer can possibly obtain from the literature available to him to determine conclusively whether or not *any* of the formations in Southern California can actually be claimed as examples of barred-basin deposits. It is suggested, tentatively, that such facies as siliceous

organic shale, diatomaceous shale, and foraminiferal shale, especially when associated with non-marine intercalations or with beds in which balanced assemblages of macroscopic fossils are absent, may repay consideration from the point of view of possible indication of the development of barred basins as an explanation for their otherwise anomalous characters.

The following features have been selected from the abundant material supplied in the monograph as *suggestions* merely for more critical examination by Californian geologists in the light of the present writer's theory.

The Moreno shales of the Coalinga district exhibit some of the characteristics expected in barred-basin deposits.

In the Eocene formations (Reed and Hollister, p. 1565), the association of "reef beds" with "white sands" and with exceptionally strong chemical weathering suggests a set of conditions comparable with those which have produced the "duricrust" of Australia. This indicates a certain degree of aridity of climate, maturity of erosion, and the possibility of development of off-shore bars, such as would give rise to the conditions postulated in the present paper. The description given on page 1572 partially confirms such an interpretation while the history of Eocene movements (p. 1573) is by no means unfavorable to the possibility of development of barred basins.

The description of the nature and distribution of the various lithological types of non-marine beds in the Sespe of the enlarged Ventura Basin, namely sandstones near the mouth and organic siliceous shale near Coalinga, is not incompatible with deposition in a barred basin.

The transgression in Miocene time might flood depressions. The occurrence of fine foraminiferal beds, even in localities where coarse deposits predominate, such as the "Gould" shale and *Valvulineria* beds (p. 1582), might provide evidence if re-examined from the new angle.

It is stated (p. 1589):

> . . . it should, however, be noticed that the several Lower Miocene foraminiferal zones now recognized have been found in comparatively few places. In other places the strata are *too coarse to yield good foraminiferal assemblages, though some of them yield excellent megascopic faunas* (italics, W.G.W.). When the exact correlation of foraminiferal and molluscan faunas becomes better known, the history of the time will become clearer in detail and a *record may be found of events not now suspected* (italics, W.G.W.).

Is it not conceivable that the absence of foraminifera may be due, not to the texture of the coarser beds, but to the fact that such beds represent deposits during periods of bar failure, while the finer foraminif-

eral beds were laid down in a barred basin into which plankton only was being swept by an inflow current?

In the San Rafael and Santa Ynez Mountain area, the Lower Cretaceous beds present some of the characters which have been suggested as diagnostic of barred-basin deposits. The presence of concretions (p. 1636) should be noted. In nearly every formation in this particular area there are suggestions that a consideration of the possibility of recurrent existence of barred basins might be profitable. This is notably the case in relation to the Oligocene and Miocene formations.

The account given of earth movements in this sector does not necessarily indicate the existence of a bar, but suggests one of the possible modes of bar formation in so highly plastic an area as Southern California was and is, namely, local cross-warping.

During Lower Miocene and Pliocene time siliceous shale and diatomaceous beds *may* have been deposited under the conditions visualized.

Of all the units described by Reed and Hollister, the Ventura Basin appears to offer the closest analogies with those of a barred basin. The possibility of existence of an effective bar opening at the "Santa Barbara strait" is considerable, and the marked variability in facies of the deposits in the basin is striking.

Two quotations from page 1644 may serve to show that consideration of the possible application to this region of the barred-basin hypothesis might not be unprofitable.

> The thickness-changes of the Miocene are particularly interesting, since they show clearly the beginning of the tendency of the old, crescent-shaped embayment to break up into *basins and barriers* (italics, W.G.W.).

This explicitly indicates the existence of structures of the type under discussion without specifically considering all the implications of such a type of structure.

> The lithology and paleontology of these beds has been described in many publications, and need not be summarized here. It will be sufficient to point out that the maximum thicknesses as measured by many geologists lie between 15,000 and 20,000 feet, and that the foraminiferal work strongly suggests a depth of water of several thousand feet during the deposition of the Lower Pliocene (Repetto) strata. Since the physical characteristics of the strata have been interpreted to mean deposition in shallow marine water, disagreements of interpretation—in which, strange as it may seem, paleontologists have generally argued for shallow water, geologists for deep—have been numerous and the results indecisive.

While it may savor of impertinence for an "outsider" to enter this field, the following suggestion is put forward with great diffidence.

Wherever there is marked conflict in interpretation of lithological (paleogeographic) and/or faunal (paleoclimatic) features as between field geologists and micro-paleontologists, an examination of the possible implications of the bar theory is called for. In the case of the Pliocene deposits of the Ventura Basin we have the paleogeographic conditions (Reed and Hollister's "Santa Barbara strait") favoring bar development, and sharp divergence of opinion between students of the problem. It is possible that some of the discrepancies may be removed if it is assumed that the deposits took place, not in abysmal depths in the open sea, but in a barred basin into which the microfossils may have been drifted by an inflow current.

In considering this question, the descriptions of both the Ventura and Los Angeles basins indicate that abysmal conditions are quite compatible with the evidence supplied by the enormous thickness of the formations. No mention is made of fossils other than foraminifera apparently of abysmal type. However, even in abysmal formations *in the open sea* one would expect a *balanced assemblage* of benthonic types, and other fossils might be looked for. Their absence *may* be a very important fact.

The *mechanical* problem of supply of sediment to an oceanic abyss in sufficient quantities to account for the enormous accumulations recorded in these basins is exceedingly difficult. Such mechanical difficulty is not encountered in seeking to explain the deposits as those of a barred basin. Further, the paleogeography described by Reed and Hollister appears to indicate the existence of almost landlocked basins, within which the development of an abysmal fauna is hard to visualize.

As pointed out elsewhere in the present paper, inferences as to abysmal depth conditions of sedimentation are likely to be erroneous. Extreme fineness of texture and paper-thin lamination are the results of *tranquillity*. Such absence of turbulence, while encountered most widely *at the present day* in abysmal depths, is equally characteristic of true barred basins.

The close analogy between the Ventura and Los Angeles basins and the Maricopa Basin is emphasized by the authors of the monograph. In the latter basin, where the beds are at least as thick as they are in the other two, foraminifera appear to be absent. The interlamination of non-marine facies points conclusively to an *oscillatory* deposition, easily explained on the bar theory, but demanding inconceivable earth movements if such rapid interchange between abysmal ocean depths and fresh-water conditions has to be explained by the conventional assumption of changes in sea-level owing to earth movement (p. 1603).

Within the Coalinga Basin (p. 1603) possible barred-basin conditions are suggested by the brownish and purplish siliceous and calcareous diatomaceous and foraminiferal shale of the Cretaceous.

Rapid oscillation between marine and non-marine facies in Upper Miocene and Pliocene in this area would be explained simply if barred-basin deposition could be established. The existence of a narrow strait at Priest Valley provides, at all events, a constriction between the basin and the open sea, and the change of facies recorded, from coarse sandstones near this strait to fine-grained, diatomaceous, and non-marine types within the basin itself, is at least intriguing. The occurrence of occasional mammalian fossils, as recorded, is compatible with basin conditions.

In Mohavia (p. 1619) there is strong evidence of aridity (saline deposits) associated with red and variegated beds in the Rosamond series of the Middle Miocene. Though Reed and Hollister specifically reject red-beds as criteria of aridity, their occurrence in some places is highly suggestive of such conditions. It is possible that *some* red and variegated beds are diagnostic but others are not. If so, it is important that some criterion for differentiation should be sought.

The description of the Miocene formations of Caliente Mountain (p. 1626) suggests possibilities of application of the theory of barred basins, with the likelihood of simplification of interpretation in an area where sharp differences of opinion appear to exist.

In the Los Angeles Basin the Modelo and Puente formations, being planktonic in regard to their fossil contents, *may* represent barred-basin deposits.

The characteristics of the San Onofre breccia are ascribed, in part, to aridity of climate. Since, in other parts of the region, sediments of the same age may have been deposited in barred basins, the establishment of aridity during the period may have a decisive bearing on the problem of the process of sedimentation in such basins.

The possibility of formation of a bar, under suitable topographic conditions, which, however, are apparently not fulfilled in this particular instance, by "extensive landslides and avalanches" extending laterally across a strait, is suggested incidentally by the authors' description of the mode of origin of the San Onofre breccia.

The phenomena of development of black shales, in many ancient sedimentary formations, appear to present striking analogies with those postulated for barred basins. It would appear that many or all of the anomalies noted in the descriptions of such deposits might be removed by regarding them as the products of such a mode of sedimentation. The subject can not be dealt with exhaustively here, but analysis from the point of view of the barred-basin theory, of one or

two outstanding published descriptions, may serve to indicate to what extent revision of ideas is desirable.

The discussions of the admirable papers by Hard and Ruedemann which follow may perhaps savor of destructive criticism. Nothing is further from the mind of the writer, who desires to express his great indebtedness to the authors of these papers for the enormous amount of valuable information derivable from them.

The aim of the discussion is to indicate that many of the phenomena described in these papers are susceptible of modifications in interpretation without any distortion of the facts presented, and to suggest that consideration of a conception not widely appreciated at the present time *may* serve to simplify and possibly correct some of the explanations which have resulted from a different point of view of the data.

The accusation may be levelled that such critical analysis savors of "special pleading." If, however, such an analysis succeeds in suggesting an improved explanation of objective data, the result is of evidential value.

Throughout a most important contribution by Hard (10) on "Black Shale Deposition in Central New York" there is an *implicit* application of strict uniformitarian principles, and no suggestion is made that there are likely to have been developed in the past sets of conditions which do not prevail anywhere on the earth at present. It is, the present writer believes, the neglect of such a possibility which has caused a limitation of outlook which has led to lack of appreciation of some of the features of such deposits.

The black shales under discussion are thin-bedded, contain much iron sulphide, some layers of calcareous concretions, and sandy and calcareous beds. Faunal remains are scarce, and true benthonic types are conspicuous by their absence. Those megascopic molluscan remains which are met with are thin-shelled and depauperized. Plankton forms, such as graptolites and pteropods, are *plentiful in individual layers*. Here and there beds of sandstone and conglomerate associated with coaly seams are interstratified with the shales.

Hard has collected and summarized the views expressed by many authors in connection with the origin of black shales. (See Hard's paper for details and bibliography.)

Clark suggests great depth of water and stagnant marine conditions, and refers to the observations of Andrussow in the Black Sea.

Pompeckj reaches similar conclusions in regard to the black shales of Bavaria.

Schuchert postulates closed arms of the sea and *culs de sac*, thus approximating the bar hypothesis. He visualizes the introduction of plankton by occasional storms, and thinks there was oxygen deficiency in the water due to imperfection of circulation. Hard expresses a doubt whether *culs de sac* of sufficient dimensions can be postulated. It may be pointed out, however, that the area occupied by the black shales under discussion is only 170 miles by 30 miles. Even under existing conditions, nearly enclosed basins of comparable dimensions are not uncommon, and there is no difficulty in visualizing even larger basins under conditions of flooding of extensive peneplains in the past.

Hard also argues that storms of sufficient violence to cause extensive indrift of plankton would produce such profound disturbance of the deposits in process of formation as to leave conspicuous traces in their stratification. *If* a bar existed, the sedimentation would be taking place in sheltered waters where profound disturbance could not occur. Further, it is not essential that the storms should have been always violent. As pointed out above, long continuance of onshore winds of moderate force is sufficient to cause a banking-up of the waters to an extent sufficient to cause flooding of the lagoon by sea water. Such banking up is most marked where shores and bottom are gently shelving.

In such instances the plankton, being carried in the *surface* waters, could suffer wide distribution before coming within the influence of the deeper and more toxic waters of the basin. Owing, however, to the inhospitability of the environment, the ultimate destruction of the plankton, on return to normal conditions, would be complete and rapid. This accounts well for both the episodic and the catastrophic nature of the accumulation of planktonic forms under such conditions.

Schuchert also suggests Sargasso Sea conditions but dismisses the hypothesis, "as such seas are little known." This is the limiting form of application of the strict Doctrine of Uniformity.

Ruedemann very properly insists that tranquillity of water determines such characteristics as fineness of texture and paper-thin lamination. He regards the graptolite shales of northern New York as sediments in a "zone between the agitated water, where the coarser sediments were deposited, and the dead or currentless water of the deep sea." Hard's comment is that this may explain the linear extent of some deposits, but is not applicable to those black shales which have wide distribution. As pointed out repeatedly in the present paper, this suggestion of Ruedemann, which is closely analogous with

the euxinic theory of van der Gracht, fails to account for deposits in the *open* sea, unless it can be substantiated that the universal abysmal equatorward creep of cold aërated water can be and has been inhibited for any reason. Under the conditions suggested in this case by Ruedemann it seems improbable that areas closely associated with "agitated waters" could be devoid of circulation sufficiently active to cause aëration adequate for the maintenance of balanced benthonic life.

Ulrich suggests that enclosed or stagnant conditions are unnecessary, and believes that Paleozoic graptolite shales were deposited in troughs connecting large bodies of open water. He invokes climatic conditions (refrigeration) as the cause of the faunal assemblage, on the ground that the cool climate rendered "the shores inhospitable for contemporaneous littoral and benthonic life." As has been shown repeatedly, mere low temperature modifies the type of faunal assembly, but does not exclude specially adapted forms. Rapid changes of environment, such as variation of temperature or salinity, are far more effective as obstacles to faunal colonization than is a persistently low temperature.

Grabau and O'Connell show that the graptolite shales of southern Sweden were deposited in comparatively shallow water and rest on an erosion surface. It is inferred, apparently, that this erosion surface was sub-aërial in origin. Twenhofel has rightly insisted that such surfaces may be due to submarine erosion. Similar shales in Scotland are regarded as mud deposits in tidal lagoons and on the flood plains of deltas. It is supposed that the graptolites were introduced by periodic high tides. As pointed out elsewhere in the present paper, tidal action is too strictly periodic to account satisfactorily for the marked irregularity and for the catastrophic character of such faunal assemblages. Further, tidal flooding should have introduced a more balanced assemblage than that under consideration.

Moore postulates "extremely shallow water, with sunlight promoting plant growth and aiding in partial decay, and with too little depth for circulation and effective wave or tidal agitation." It is difficult to believe that the effects of agitation in such extremely shallow waters would not be apparent in the form of ripple marks, *et cetera*. In the case of Lake Torrens in South Australia, which has a perfectly flat floor 120 miles in length, the small body of water present is driven bodily before the wind from one end of the lake to the other whenever there is a change in wind direction.

In his review of the evidence, Hard maintains that no single theory is competent to explain all occurrences, a dictum with which everyone must agree. Extremely deep and stagnant water is unneces-

sary for the deposition of black shales, but an acid and toxic environment is required, with tranquil water and deficiency of oxygen.

The paper-thin bedding so characteristic of many such deposits he ascribes to the colloidal nature of the materials, which have shrunk and been compressed perhaps to only one-fifth of their original thickness—an ingenious theory of high probability.

In this description by Hard, while it appears to comply exceedingly well with the requirements of the bar theory, there is no definite indication of the existence of such a structure. However, this may be because such a barrier has never been thought of in this connection. Search for evidence of a bar is restricted in this case, since the sediments were derived from a land surface lying at the east, and the faunal remains become more abundant and normal in character towards the west. Towards the east they become more scarce and more depauperized. The bar, if it exists at all, must therefore be sought towards or beyond the western limits of the black shale area.

In a more recent paper by Ruedemann (18) the origin of black graptolite shales is fully described.

The common characteristics of such deposits are held to be fineness of lamination, which is common but not invariable; generally extensive linear development; association of more or less numerous thinly bedded sandstones and of a few conglomerates; not uncommonly interbedding with coaly seams; dominance of planktonic forms amongst the fossils, many of wide distribution, and paucity of true benthonic forms. Any explanation of carbonaceous and bituminous shales must harmonize all these characteristics.

Ruedemann summarizes various theories which have been advanced and points out their weaknesses (see Ruedemann's paper for details and bibliography). It is unnecessary to repeat facts already referred to in consideration of Hard's views. Additional examples are the following.

Ulrich and Ruedemann regard graptolite shales as deposits in seas with free ingress and egress, because graptolites have to be introduced by currents into epicontinental seas. Such an explanation does not account for the unbalanced nature of the faunal assemblage, and introduces serious difficulties in explaining conglomerates, sandstones, coals, and other non-marine intercalations. In "deep quiet levels along coast lines" the exclusion of benthos would not be anticipated.

Marr describes the Stockdale shales of the English Lake district as deposits in two deep embayments extending from the ancestral Atlantic to Central Europe.

The waters in these embayments below the 100-fathom line, where the

black graptolite shales and the associated gray and red barren shales were deposited, were highly toxic, owing to the quietness of the bottom water, lack of vertical circulation and resulting lack of oxygenation. Great quantities of organic matter (seaweeds and planktonic animals) that have been carried into the embayments by storms and currents were dropped into the dead bottom waters. As plankton and pseudoplankton (including epiplankton) found associated in the shales are cited graptolites, certain crustaceans, and small cephalopods.

Such a description conforms with the suggestions of the present paper in all but the assumption of some form of bar. This additional assumption the writer believes to be necessary to account for the "quietness of the bottom water resulting in high toxicity." The banking-up of water by onshore storms must be compensated for and balanced by the return of that water in the form of undertow. On a uniformly graded bottom, effective circulation of the water must result. Only if there is some kind of barrier across the entrance can stagnation be caused. In an *open* arm of the sea a balanced assemblage of benthos must be developed.

Ruedemann has analyzed the faunal contents of the black Utica shales, and the succeeding gray Lorraine shale. The former contains seaweeds, sponges, graptolites, worms, cephalopods, and eurypterids. There is a marked absence of corals and crinoids. The Lorraine shale, on the other hand, shows a large percentage of bryozoans, brachiopods, pelecypods, and gastropods.

The smaller fauna of the Utica shale is chiefly plankton with an impoverished bottom fauna mostly of small forms. There are brachiopods with phosphatic shells. The fauna of the Lorraine shale is a normal, muddy-bottom fauna.

Ruedemann divides graptolite shales into two classes: "pure graptolite shales," containing essentially nothing but graptolites; and "mixed graptolite shales," containing in addition to graptolites a generally scanty and impoverished bottom fauna.

Richter's views on the Devonian Hunrückschiefer of Germany are mentioned. It is generally considered that this formation was deposited in deep toxic waters, and that its fossils were dropped into this quiet water. Richter shows, however, that the water was definitely in motion, as is proved by the presence of ripple marks, cross-bedding, sandstone lenses, and by the drifted position of the arms of crinoids and starfishes. In *some places* there are numerous branching worm burrows, and *impressions* of pelecypods, gastropods, trilobites, *et cetera*, showing that there was, *locally and temporarily*, a rich benthonic fauna. The absence of tests of these benthonic forms is explained by "selective diagenesis" of the hard parts which were dis-

solved before they could be protected by burial. Only those which were pyritized were preserved.

In regard to this description it may be pointed out that the evidences of movement suggest shallow water. The apparently episodic occurrence of benthonic forms points to only local and occasional development of open-water conditions, one explanation of which could be as the result of occasional bar failures. "Selective diagenesis" indicates solvent conditions which are not generally associated with the normal processes of the sea bottom, but which are quite comprehensible in the acid waters of a closed basin. The pyritization mentioned is also compatible with the early stages of re-concentration of sea water in a barred basin immediately after a marine incursion, when accessions of iron salts may have been received.

Ruedemann's main thesis in the paper under discussion is that the rare occurrences of fossils found associated with graptolites indicate that

> in character, composition, relative size, etc., they closely correspond to the present fauna of the sargassum-weeds in the Sargasso Sea, and that the graptolites as a whole belong to the pseudoplankton. They drifted far and wide attached to the Paleozoic seaweeds and formed sargasso meadows in the *central parts of the Atlantic and Pacific oceans* (italics, W.G.W.). They were carried into the embayments and epicontinental seas, and there were deposited with the black muds.

It may be commented that sargasso conditions sufficiently explain some of the fauna and flora of the black shales, but break down completely in explaining the *occasional, local and temporary* intercalations of conglomerates, coarse sandstones, and coaly deposits in such formations. The very nature of the Sargasso Sea demands a position far removed from continental land, as indicated in the above quotation, and the isolation of the area by a "ring current" about its periphery. It *may* be possible for conditions to exist within this circle favorable to the deposition of black shales in toxic bottom waters, though even this requires proof. The sargasso conditions themselves, however, set a limit to the outward drift of abundant plankton from the vortex, and it is inconceivable that such drift could reach the necessarily distant *loci* of deposition visualized by Ruedemann: If it did so, the organisms introduced by drift should be deposited *in association with those indigenous to the area of deposition* unless we are to credit the floating plankton with an entirely improbable power of selection of place of interment.

The other points raised by Ruedemann in this valuable and suggestive paper may be dealt with briefly. The catastrophic destruction

of organisms, as evidenced by their episodic distribution and by the presence of noteworthy proportions of immature forms, is accounted for on the sargasso hypothesis as the effect of storms breaking up the seaweed rafts and floating colonies. It seems likely, however, that storms are of such frequent occurrence that individual contributions from such a source could not be distinguished from one another, especially under the necessarily slow rate of accumulation of sediments in the central oceanic areas where alone sargasso conditions can prevail. In other words, geologically speaking, oceanic storms are practically continuous and not occasional phenomena.

The breaking down of the effective control by a bar of ingress into a partially closed basin may account more satisfactorily for all the features referred to, and is likely to be an event far less frequent than the occurrence of even great storms.

The absence of scavengers is essential to account for the preservation of the sunken fauna. It remains to be proved, however, that such scavengers are absent from the sea bottom under sargasso conditions. The absence of any effective barrier to deep abysmal circulation would seem to indicate the strong probability that the deep waters of a Sargasso Sea may still be effectively aërated.

The absence of oxygenating currents is proved by the lack of parallelism in the graptolite remains in "pure graptolite shales," but such parallelism is present in "mixed graptolite shales." Barred-basin conditions appear to account quite satisfactorily for *both* absence of oxygen and absence of currents.

Pyritization is regarded as characteristic of sargasso conditions. It is certainly one of the most outstanding features in barred basins.

Pure black graptolite shales are commonly thin-bedded. The graptolites are generally spread out on bedding planes. They are rarely or not at all *within* the shale laminae. The bedding planes represent *cessation* of movement, indicating periods of greater quiescence. In a barred basin it is to be expected that, after the disturbance caused by an irruption of sea water, mechanical sediment is likely to settle more rapidly than the lighter organic matter, whose buoyancy is increased both by its specifically large surface and by evolution of gases due to incipient putrefaction. Hard's description of occasional linear deposits of sand grains is instructive.

Conditions of quietude are assured in the barred basin. This argument, however, is applicable to sargasso conditions as well, and is not here emphasized as a strong support for the bar theory as are many of the others.

Continuity of development is claimed for the Shagticoke, Deep

Hill, and Normanskill shales. Is physical continuity in this case proved without any breaks due to erosion or burying? Even if there is absolute physical continuity from Newfoundland to Alabama, as claimed, there is no difficulty in visualizing a Mediterranean of these dimensions under a set of paleogeographic conditions different from those prevailing at the present day. If such a barred basin existed, it would be closed by a structural bar rather than a sedimentary one. Ruedemann gives an account of the marked differences of sedimentation between the contemporary Levis and Chazy troughs. This account may be accepted as a complete case of barred-basin development, but not of the open-channel conditions postulated by Ruedemann. *If* an open channel existed in the case of the Levis trough, what prevented the development there of a *balanced* fauna with bottom scavengers? In the parallel Chazy trough the normal assemblage is actually present, and some *abnormal* conditions must have existed to prevent the development in the Levis trough of formations similar to those in the Chazy trough.

Ruedemann says:

> Even if one should be inclined to accept the view that the graptolites were deposited in small quiet embayments, shore lagoons, etc., and even if one should cite the possible patchy distribution (not yet proven, however) of the graptolites as favoring this view, one has still to assume continuous lagoons and embayments along coasts stretching the full length of the continent—an assumption which would be as exaggerated as Grabau and O'Connell's chart of a series of continuous adjoining deltas to explain the great series of Scotch graptolite beds.

That Ruedemann considers "the possible patchy distribution" as feasible is indicated by his own parenthesis.

It is part of the thesis of this paper that we must visualize some extensions of the strict Doctrine of Uniformity. Admittedly we can not, at the present time, point to any barred basin of the dimensions required by the Levis trough. If it comes to that, we have no examples of the "wide embayment or intracontinental channel" postulated by Ruedemann on a scale comparable with the Levis trough. It is not necessary to assume that there was a series of *coastal lagoons* separated from the ocean by sand spits similar to those on parts of the Atlantic coast of the United States to-day. The barrier which accounts for Ruedemann's Levis trough is all that is necessary except that a *partial* blockage at each end is needed to explain the exclusion from the Levis trough of the balanced fauna and the normal sedimentation which is characteristic of the parallel Chazy trough, which, by contrast, was presumably open.

"Great thickness of beds and great series of faunas argue for continuity of sedimentation as against 'local embayments'." Certainly temporary local embayments of the type exemplified by the lagoons of the existing Atlantic coast are inadequate. There is, however, no difficulty in picturing the persistence of *structural* basins like the Levis trough. The barred-basin theory here presented is a protest against undue limitation of conception of past geological conditions *in cases where adequate evidence to the contrary can be adduced.* The persistence of the Levis and Chazy troughs is a *proved fact.* The only difficulty in such a case is in postulation of continuance of barred conditions. The fact that the nature of the sediments continues apparently unchanged in both cases, provides objective proof of the persistence of the same environmental conditions, whatever they may have been.

The absence of planktonic fauna in the Marcellus black shale "save the common *Styliolina fissurella,*" suggests that this Marcellus epicontinental sea had no such wide-open connection with the ocean as had the Ordovician graptolite-shale-forming seas. The graptolites had become extinct. Does it not rather suggest that the conditions were essentially the same, but that, at the particular period involved, the bulk of the plankton was devoid of hard parts, as is the case at the present day, and that, though there was ample protoplasmic material available to account for the organic matter in the shales, there were in Marcellus time no organisms like the graptolites possessed of structures capable of permanent preservation as fossils?

The writer is incompetent to comment upon Ruedemann's discussion of the ecology of the eurypterids. As they were free-swimming organisms, and probably the dominant type of such organisms at the period of their maximum development, there is no reason why they should not be swept into the toxic environment of the basins, just as are seals and fish into Karabugas at the present time.

POSTSCRIPT

The study of several interesting papers since the manuscript of the foregoing paper was despatched has suggested the desirability of adding a short postscript to emphasize certain points which have more or less been taken for granted previously, but which, in the light of these reports, seem to require more specific statement.

1. The impression was gained previously that most investigators at the present time hold that reservoir rocks are rarely the source rocks of the oil which they contain,—in other words, that oil deposits are rarely strictly autochthonous. That this is far from being the

fact is shown by the specific statements of Kalitski (34). He stands solidly for genesis of oil from growths of sea grasses (which he distinguishes sharply from seaweed in the ordinary acceptance of the latter term), strictly *in situ*, in the actual sedimentary environment in which the resulting oil is now found. The writer is unable to accept his arguments in favor either of the origin of oil exclusively from this type of marine vegetation, or of strictly autochthonous formation, or of the conditions of deposition postulated.

The parallelism between distribution of oil and distribution of growth *in situ* of marine vegetation applies just as directly to the consideration of *any* type of marine organisms, plant or animal, sessile or free. Kalitski does not prove at all conclusively that *preservation* of the organic material is possible under the conditions postulated; in fact, his reference (p. 11) to the work of Trask indicates specifically that the latter has proved broadly an inverse ratio between the quantity of organic matter in a deposit and the coarseness of texture of the sediment. Yet he looks to sandy and calcareous sea floors as the *loci* for both growth and accumulation of the marine vegetation.

He mentions incidentally that partially closed marine basins are most favorable for accumulation of sea grasses but does not analyze the conditions of deposition in such basins.

The thesis of the present writer is that conditions of benthonic growth of organisms are, in their very nature, conditions unfavorable for adequate preservation of a sufficiency of organic matter for the genesis of petroleum.

Like Krejci-Graf (13), Kalitski emphasizes the fact that chlorophyll derivatives have been recognized in many oils, but goes further than the former, and regards this as a proof that the material is entirely of vegetable origin.

2. The mobility of petroleum must be considered at every point. It accounts for most of the apparent anomalies in distribution which are encountered in practice.

The "patchy" distribution of oil in sands which are in direct association with shaly beds in which organic matter is uniform and abundant (Kalitski, p. 12 quoting Archangelski), as in the North Caucasus region, need cause no surprise if it be granted that *migration* of the oil within porous beds is controlled by accidents of structure and arrangement of the latter.

The probability that migration has been largely or entirely responsible for accumulations of economically important dimensions must be recognized and remembered. In the writer's paper attention has been confined to primary and autochthonous deposits only, that

is, specifically, to *source* rocks and not to actual accumulations in reservoir rocks.

In this connection the demand of Krejci-Graf (35) that a *general law* applicable to *all* cases must be sought and found may be impossible of realization. The writer's impression is that a substance of such relative chemical simplicity as oil is likely to have been formed in nature under a variety of different conditions, of which those of the barred basin constitute only one type. Probably all that can be expected in the objective sought by Krejci-Graf is the determination of a group of general principles, of which a *selection* must be made to explain each individual case on its merits.

3. The paper by Ermisch (33) suggests the desirability of emphasizing to some extent certain features of the association of salt and oil. The writer firmly believes that this relation is a genetic one, and that many of the difficulties in explanation of such an association are removed by accepting the bar theory or its equivalent.

Ermisch comments on the variability in association of oil with salt deposits, but neglects a very important factor, namely, the mobility of *both* substances. Oil can migrate under the control of gravitation, on account of its fluidity. Because of its plasticity, salt can be set in motion by tectonic stress.

It is only primary, autochthonous salt and oil deposits which can be expected to remain in their original relationships. When either migrates the association is destroyed. The major salt deposits of Europe to which Ermisch refers are "exzeme" in structure, and the same origin is claimed for those of Colombia. The stresses which caused the injection of the salt masses must have produced conditions favorable for the migration of any associated oil. An original association is not to be expected in such a case. It is quite conceivable, however, that, in a large proportion of cases of "exzeme" salt injection, the oil primarily associated with the original salt deposit may have followed the same route as the salt in its migrations, the fluid oil following lines of weakness opened by the plastic salt, giving rise to a secondary association of the two substances. Secondary association of this kind demands coincidence of so many variable factors that absence of such a relationship in a particular case need cause no surprise.

The communication of Krejci-Graf and Leipert (36) on bromine association with bituminous materials, taken in conjunction with Tageewa's paper cited previously (20), suggests another possibility to which due weight has not been given. While there is apparently a fundamental and genetic association between the salts of sea water and source material of oil deposits, it is only in cases of very advanced

desiccation of the basins that inclusion of considerable amounts of the rarer salts can be expected. As suggested in the writer's paper, indrift and destruction of plankton commence in the very early stages of the existence of the barred basin in suitable climatic environment. In such cases the saline content of the deposits must be low.

A probable cause for the observed variability in quantitative association of bromides and iodides with bituminous deposits is suggested by the data supplied by Krejci-Graf (36) in relation to the *selective* capacity exhibited by organisms in relation to these and similar substances. All that is necessary to obtain noteworthy content of one of these elements is to have a supply, amongst the plankton, of some organism or organisms possessing high specific power of absorption of that element.

Is it possible to conclude from the marked difference between paraffinic and asphaltic oils as regards their bromine content that they were derived from fundamentally different types of plankton?

4. The views of Müller, discussed by Krejci-Graf (35), in regard to the apparent antagonism between oil and lime, suggest a further consideration in relation to the fossil content of euxinic deposits. Müller has been led to the probably incorrect conclusion that the presence of siliceous organisms is essential to oil development. This fallacy is dealt with by Krejci-Graf. Is it not highly probable that the really essential fact in many cases is that the highly acid waters of an *advanced* stage in the development of euxinic conditions are responsible for *selective* solution of the hard parts of planktonic organisms, calcareous forms losing their skeletons, while siliceous and chitinous forms retain theirs? In such a case, though the calcareous forms may be even more abundant than the others, they can leave no permanent record of their presence. One might parody the words of St. Paul and say that "the things which are seen are accidental, but the things which are not seen are essential."

5. Finally, the writer wishes again and more definitely to draw attention to the fact that, while the structural features involved are vital to the development of a barred basin, the climatic environment is no less fundamental in determining the nature and extent of the organic deposits in the basin. For the development of those euxinic conditions which the writer believes to be essential to the development of the true sapropels which are to be regarded as the source materials of oil, it seems inevitable that low atmospheric humidity, favored by aridity of climate, must be a vitally important factor, controlling as it does the maintenance of the inflow current, on which depends the introduction of organic matter, in adequate quantities, into the toxic

and preservative environment of the basin, itself incapable of habitation by aquatic organisms.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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STRATIGRAPHY OF NORTHERN EXTENSION OF BURLINGTON LIMESTONE IN MISSOURI AND IOWA[1]

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ABSTRACT

Evidence is presented in favor of the retention of the terms Osage and Meramec as subseries in the standard classification of the Mississippian series of the Carboniferous system. Definite, easily recognizable, stratigraphic life zones are established in the Burlington formation of northeastern Missouri and southeastern Iowa. The subdivisions of the Burlington limestone transgressively overlap against the underlying formations toward the north. Each of the zones of the Burlington limestone, from the base upward, is found successively in contact with underlying formations in the area between Louisiana, Missouri, and Kalona, Iowa.

INTRODUCTION

During the past 8 years the writer has made an attempt to study in detail the formations of the Osage subseries of the Mississippian rocks as they crop out throughout the Mississippi Valley region. During the field seasons of 1928 and 1929 a detailed stratigraphic analysis of the Burlington limestone was made from Pike county, Missouri, to its northernmost exposures in Iowa.

The Mississippian series of North America is divided into four subseries: Kinderhook at the base, followed by Osage, Meramec, and Chester at the top. The term Valmeyer was recently introduced by Moore[3] and defined to include the Osage and Meramec rocks. The writer can not subscribe to this classification for the following reasons: by far the greatest faunal break in the Mississippian succession occurs at the top of the Osage subseries; the crinoid-brachiopod faunas of the early Mississippian pass from the picture with startling suddenness; among the crinoids, particularly, the rapid specialization of the early Mississippian is followed by wholesale extinction not only of species but of genera; the typical *Composita-Pentremites-Archimedes* fauna that ranges throughout the late Mississippian makes its appearance in the base of the Meramec subseries; the faunas of the Meramec, Chester, and Morrow beds are much more closely allied with the Upper Carboniferous than with the underlying Mississippian; the

[1] Manuscript received, April 13, 1937.

[2] University of Tulsa.

[3] R. C. Moore, " 'Carboniferous' Rocks of North America," *Sixteenth International Geological Congress Report*, Vol. 1 (1933), p. 595.

Meramec formations are everywhere unconformable on the underlying Osage and older rocks; as regards distribution, the Kinderhook and Osage beds are closely related to the western early Mississippian seas, whereas the Meramec formations are normally limited to the areas in which are found Chester and Morrow formations, showing that the distribution of the Meramec with respect to the late Osage beds is decidedly different; the gray, massive, non-cherty limestones of the Meramec subseries make as definite a lithologic unit as is found anywhere in the stratigraphic column; the lens and pocket type of sedimentation with its rapid lateral gradations, so characteristic of Chester, Morrow, and later Paleozoic formations, makes its appearance in late Ste. Genevieve time. It appears to the writer that overwhelming evidence opposes the combining of the Osage and Meramec deposits to form a unit such as the proposed Valmeyer. R. C. Moore[4] has recently indicated that he is entirely in accord with the view here expressed. He also points out the close correspondence of the dividing line between Meramec and Osage rocks in America with the boundary between Tournaisian and Visean in Lower Carboniferous rocks of Europe and he believes that the break in deposition at this horizon that is observed in both continents is a very significant one.

The Osage beds of the Mississippi Valley and Mid-Continent region consist normally of exceptionally crinoidal cherty limestone, interbedded with minor amounts of marly shale. Four divisions of the Osage subseries are commonly recognized: the Fern Glen and its equivalents at the base, followed by Burlington, Keokuk, and Warsaw, in ascending order.

The basal Osage is represented in southeastern Missouri by the Fern Glen formation, in northeastern and central Missouri by the Sedalia limestone, and in southwestern Missouri, northwestern Arkansas, and Oklahoma by the St. Joe and Reeds Spring limestones, in Kentucky and Tennessee by the New Providence shale, and in New Mexico by the Lake Valley limestone. Equivalent horizons appear well up in the sections of the Madison limestone in much of the Rocky Mountain province. This is by far the most widespread part of the Osage subseries. The lithologic character of these early Osage beds, except in the Rocky Mountain province, is exceptionally crinoidal limestone interbedded with very fossiliferous marly shales. The proportion of shale to limestone increases toward the east. A considerable number of the invertebrate species that occur in the basal Osage formations continue upward into the Burlington limestone. When faunal assemblages are considered, the basal Osage formations are

[4] Oral communication.

easily distinguishable by this character alone. The following species occur commonly in the basal Osage rocks: *Cyathaxonia arcuata* Weller, *Evactinopora sexradiata* Meek and Worthen, *Schizoblastus moorei* Cline, *Agaricocrinus praecursor* Rowley, *Actinocrinus arrosus* (S. A. Miller), *Spirifer rowleyi* Weller, *Athyris lamellosa* (Leveille), *Rhipidomella oweni* Hall and Clarke, *Brachythyris suborbicularis* (Hall), *Cliothyridina prouti* (Swallow), and *Cliothyridina incrassata* (Hall). The faunas in the Rocky Mountain area are not so easily separable, because many later Osage species and genera occur intermingled with typical basal Osage forms. It becomes increasingly clear that the faunas migrated from the western seas into the Mississippi Valley province.

The Burlington limestone is much less widely distributed than the underlying basal Osage formations. It is well exposed in western Illinois, southeastern Iowa, northeastern, central, and southwestern Missouri, and northern Arkansas. In Indiana, Kentucky, and Tennessee the New Providence shale of early Osage age is commonly followed directly by beds of Keokuk age. In Oklahoma the Burlington limestone is present only locally and in this area it lies between the Reeds Spring limestone below and the Keokuk limestone above. An excellent upper Burlington fauna has recently been reported by Stoyanow[5] from the Mississippian limestones of Arizona. The upper Burlington index fossil, *Pentremites elongatus* (Shumard), was recently identified in a well core taken from the Sinclair Gentry No. 1, in Kansas, in Sec. 1, T. 33 S., R. 15 W., at a depth of 4,851–4,861 feet. An excellent specimen of *Spirifer grimesi* Hall was also found in the same well core. Lithologically the Burlington consists of crinoidal cherty limestone that weathers brown. The fauna of the Burlington is exceptionally large and diversified. The following relatively commonly occurring species range throughout the entire Burlington limestone: *Spirifer grimesi* Hall, *Productus burlingtonensis* Hall, *Brachythyris suborbicularis* (Hall), *Zaphrentis centralis* Milne Edwards and Haime, *Uperocrinus pyriformis* (Shumard), *Eutrochocrinus christyi* (Shumard), and *Macrocrinus verneuilianus* (Shumard). A large part of the Burlington fauna has a relatively short vertical range.

The Keokuk formation is more widely distributed in the Mississippi Valley province than the underlying Burlington limestone. As yet, the Keokuk and Warsaw have not been definitely identified in the Rocky Mountain province. Beds of Keokuk age are well exposed in southeastern Iowa, Missouri, northeastern Oklahoma, northern

[5] A. A. Stoyanow, "Correlation of Arizona Paleozoic Formations," *Bull. Geol. Soc. America*, Vol. 47 (1936), p. 507.

Arkansas, southern Indiana, Kentucky, Tennessee, and Alabama. Lithologically the Keokuk consists of bluish gray, cherty, crinoidal limestone that becomes shaly in the northern areas of Iowa and Indiana. There is a distinct faunal break between the Keokuk and the underlying Burlington limestone. Many of the Keokuk genera are derived from the underlying Burlington, but few species cross the line. The following species occur commonly in almost all areas in which the Keokuk is exposed: *Tetracamera subtrigona* (Meek and Worthen), *Spirifer logani* Hall, *Orthotetes keokuk* Hall, *Spirifer keokuk* Hall, and *Actinocrinus lowei* Hall. The remarkable development of crinoids such as those found at Crawfordsville, Indiana, appears to be local within the Keokuk beds.

The Warsaw formation, at the type locality in western Illinois, includes shale and impure limestone that was deposited in the diminishing sea of late Osage time in the Mississippi Valley province. Its distribution has been greatly overestimated. Practically all the species found in the Warsaw beds occur also in the underlying Keokuk strata. *Archimedes owenanus*, often considered as a Warsaw index fossil, occurs also in the shaley limestone at the top of the Keokuk.

STRATIGRAPHY

Because of the limited vertical range of most of the species of Burlington crinoids, it is possible to establish very definite life zones within the formation. Fossil crinoids are still to be found in large numbers in the Burlington limestone wherever weathered surfaces occur. During the past few years the writer has collected more than 5,000 specimens, representing more than 150 species, from these weathered surfaces.

LIFE ZONES IN BURLINGTON LIMESTONE

7 *Pentremites elongatus* zone
6 *Dizygocrinus rotundus* zone
5 *Physetocrinus ventricosus* zone
4 *Cactocrinus proboscidialis* zone
3 *Cryptoblastus melo* zone
2 *Uperocrinus longirostris* zone
1 *Batocrinus calvini* zone

In establishing life zones in the Burlington limestone no effort is made to list all species which occur in these zones, but rather to record commonly occurring forms, the assemblage of which defines the zone. Many of the zones used in this report were recognized by Rowley[6] as early as 1907.

[6] R. R. Rowley, "Geology of Pike County," *Missouri Bur. Geol. and Mines*, Vol. VIII, 2nd ser., p. 36.

Batocrinus calvini zone.—This zone consists of massive, soft, brown, crinoidal limestone interbedded with yellow dolomitic shale, carrying minor amounts of chert. *Batocrinus calvini* Rowley is confined to this zone, and occurs abundantly. *Agaricocrinus pyramidatus* (Hall), *Cactocrinus multibrachiatus* (Hall), *C. extensus* Wachsmuth and Springer, *Physetocrinus lobatus* Wachsmuth and Springer, and *P. ornatus* (Hall), are associated with *B. calvini.*

Uperocrinus longirostris zone.—Thin-bedded, brown, fine-grained, crinoidal limestone with minor amounts of chert compose this zone. It contains abundant specimens of *Uperocrinus longirostris* (Hall), and in association with this species is *Batocrinus subaequalis* (McChesney), *B. aequalis* (Hall), *B. lepidus* (Hall), *Macrocrinus gemmiformis* (Hall), *M. carica* (Hall), *Eretmocrinus nodosus* Wachsmuth and Springer, *E. rugosus* Wachsmuth and Springer, and *Dorycrinus unicornis* (Owen and Shumard).

Cryptoblastus melo zone.—This zone is made up of very soft, brown, shaly, exceptionally crinoidal limestone. It is the most prolific crinoid horizon in the formation. Most of the species of the *Uperocrinus* zone occur here but the zone is distinguished by the large numbers of specimens of *Cryptoblastus melo* Owen and Shumard, and *Orophocrinus stelliformis* Shumard, the latter being definitely confined to this zone.

Cactocrinus proboscidialis zone.—This is the so-called "White Ledge" of quarrymen, which is extensively mined in Pike County, Missouri, for cement. It is a massive, gray, crinoidal limestone, relatively free from chert. Most of the lower Burlington species of *Cactocrinus* occur in this zone. Common species are *Cactocrinus proboscidialis* (Hall), *C. multibrachiatus* (Hall), *C. clarus* (Hall), *C. reticulatus* (Hall), *Decadocrinus rudis* (Miller and Gurley), *D. perplexus* (Meek and Worthen), *Cyathocrinus fragilis* Miller and Gurley.

Physetocrinus ventricosus zone.—This zone is composed of thin-bedded, very cherty, crinoidal limestone that varies in hardness and in many places is dolomitic. Characteristic fossils are *Rhodocrinus barrisi* Hall, *Macrocrinus konincki* (Shumard), *Uperocrinus aequibrachiatus* (McChesney), *Agaricocrinus planoconvexus* (Hall), *Periechocrinus whitei* (Hall), *Actinocrinus scitulus* Meek and Worthen, *Cactocrinus caelatus* (Hall), *Physetocrinus ventricosus* (Hall), *Platycrinus nodostriatus* Wachsmuth and Springer, and *P. excavatus* Hall.

Dizygocrinus rotundus zone.—Massive, green, glauconitic, cherty limestone composes this zone. Its fauna is not represented in Pike County, Missouri, but it is the most easily recognized of the zones in southeastern Iowa, and has been traced through central and southwestern Missouri. Typical fossils are *Dizygocrinus rotundus* (Yandell

and Shumard), *D. dodecadactylus* (Meek and Worthen), *Eretmocrinus calyculoides* (Hall), *Agaricocrinus bellatrema* (Hall), and *A. inflatus* (Hall).

Pentremites elongatus zone.—This zone is made up of thin-bedded, gray, very cherty, exceptionally crinoidal limestone. It is a very pro-

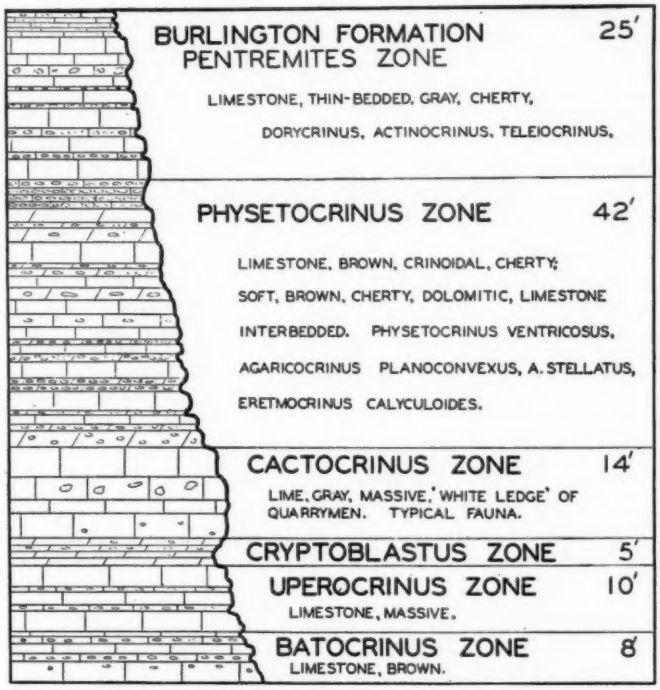

FIG. 1.—Burlington section, Pike County, Missouri. Figures in this and following sections indicate thickness in feet.

lific crinoid horizon containing as characteristic species *Pentremites elongatus* (Shumard), *Dorycrinus cornigerus* (Hall), *Actinocrinus multiradiatus* Shumard, *A. verrucosus* Hall, *Cactocrinus glans* (Hall), *Amphoracrinus divergens* (Hall), *Strotocrinus regalis* (Hall), and *Teleiocrinus umbrosus* (Hall).

The Burlington formation is exceptionally fossiliferous in the region around Hannibal and Louisiana, Missouri. Great numbers of excellently preserved crinoids may be collected from the brown weath-

ered zones in the section. Hydraulic stripping in the large Atlas cement quarries 6 miles south of Hannibal has made available tremendous numbers of excellent crinoid specimens.

The *Cryptoblastus* zone is exceptionally fossiliferous in the Hannibal and Louisiana quarries. The very beautifully preserved white

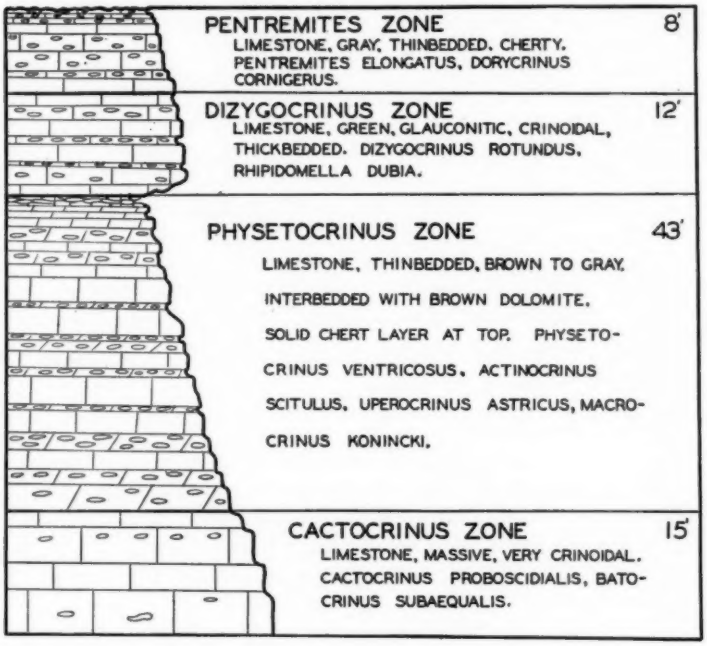
PENTREMITES ZONE
8'
LIMESTONE, GRAY, THINBEDDED, CHERTY.
PENTREMITES ELONGATUS, DORYCRINUS CORNIGERUS.
DIZYGOCRINUS ZONE
12'
LIMESTONE, GREEN, GLAUCONITIC, CRINOIDAL, THICKBEDDED. DIZYGOCRINUS ROTUNDUS, RHIPIDOMELLA DUBIA.
PHYSETOCRINUS ZONE
43'
LIMESTONE, THINBEDDED, BROWN TO GRAY, INTERBEDDED WITH BROWN DOLOMITE. SOLID CHERT LAYER AT TOP. PHYSETOCRINUS VENTRICOSUS, ACTINOCRINUS SCITULUS, UPEROCRINUS ASTRICUS, MACROCRINUS KONINCKI.
CACTOCRINUS ZONE
15'
LIMESTONE, MASSIVE, VERY CRINOIDAL. CACTOCRINUS PROBOSCIDIALIS, BATOCRINUS SUBAEQUALIS.

FIG. 2.—Burlington type section, Burlington, Iowa.

chert crinoids collected by the late Professor R. R. Rowley came from the *Cryptoblastus* zone in the quarries at Louisiana, Missouri.

Parts of the *Physetocrinus* zone are exceptionally fossiliferous, particularly in the Louisiana quarries. *Agaricocrinus planoconvexus* occurs in great numbers in the upper part of this zone.

The *Dizygocrinus* fauna is only partly represented in this part of Missouri. The green glauconitic limestone ledges, so diagnostic of the zone in Iowa, are not present and *Dizygocrinus* occurs only rarely. In the upper part of the *Pentremites* zone the highly specialized late Burlington species appear in profusion. The lower part of the *Pen-*

tremites zone at Hannibal is undoubtedly to be correlated with the *Dizygocrinus* zone of Iowa.

Northward from Hannibal along the bluffs of the Mississippi River, the Burlington limestone dips beneath the surface in a shallow syncline, the Keokuk limestone being exposed in the axis of the syncline. The Burlington beds reappear north of Keokuk and are excellently exposed in the type section at Burlington, Iowa.

At Burlington the *Cactocrinus* zone consists of very massive ledges of crinoidal limestone. The many species of *Cactocrinus* described by Wachsmuth and Springer came from quarries developed in these lower ledges.

The *Physetocrinus* zone is relatively soft and exceptionally cherty. As a result it is poorly exposed and occupies a retreating part of the cliff between the massive overlying *Dizygocrinus* beds and the underlying *Cactocrinus* beds. It is marked at the top by an exceptionally thick layer of chert. The dolomitic ledges immediately below the chert carry *Macrocrinus koninckí* in abundance.

The *Dizygocrinus* zone consists of massive, green, glauconitic, crinoidal limestone which is relatively free from chert. It forms an overhanging ledge in almost all parts of the area. The basal part of the zone is characterized by *Hadrophyllum glans*, which occurs in abundance and appears to be restricted to this part of the section.

The *Pentremites* zone is less glauconitic, thinner-bedded, gray, and more cherty. The highly specialized upper Burlington species appear in abundance. The uppermost beds of the zone are characterized by *Dorycrinus cornigerus* (Hall), *Teleiocrinus umbrosus* (Hall), *Actinocrinus verrucosus* Hall, *A. multiradiatus* Shumard, and *Strotocrinus glyptus* (Hall).

The Burlington limestone may be traced northward along the bluffs of the Mississippi River to the mouth of the Iowa River, but no Burlington exposures are known farther north in the Mississippi River bluffs. Excellent exposures are present along the south bluff of the Iowa River in Louisa County, Iowa.

The beds of the *Physetocrinus* zone are slightly more dolomitic in this region. *Macrocrinus koninckí* (Shumard) occurs in abundance in the upper ledges of the zone. The thick, massive chert layer which marks the contact between the *Physetocrinus* and *Dizygocrinus* zones, is excellently developed. The *Dizygocrinus* zone is the most conspicuous part of the section in this region, and it is also much more fossiliferous than farther south. Besides the crinoid fauna of this zone, *Zaphrentis calceola* (White and Whitfield), *Palaecis obtusus* (Meek and Worthen), *Rhipidomella dubia* (Hall), and *R. burlingtonensis*

(Hall) occur abundantly. The *Pentremites* zone is fully developed and exceptionally fossiliferous. Several colonies of crinoids preserving stem and arms have been discovered in this region.

Northwestward from Morning Sun, Iowa, the Burlington limestone is poorly exposed. Exposures of the *Dizygocrinus* zone are fairly good in the beds of many of the small creeks cutting back from the Iowa River. The northernmost exposure of Burlington beds is located

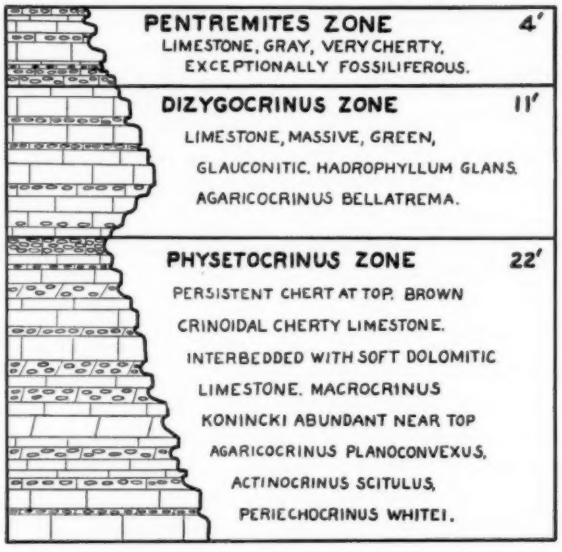
PENTREMITES ZONE 4'
LIMESTONE, GRAY, VERY CHERTY, EXCEPTIONALLY FOSSILIFEROUS.
DIZYGOCRINUS ZONE 11'
LIMESTONE, MASSIVE, GREEN, GLAUCONITIC. HADROPHYLLUM GLANS. AGARICOCRINUS BELLATREMA.
PHYSETOCRINUS ZONE 22'
PERSISTENT CHERT AT TOP. BROWN CRINOIDAL CHERTY LIMESTONE. INTERBEDDED WITH SOFT DOLOMITIC LIMESTONE. MACROCRINUS KONINCKI ABUNDANT NEAR TOP AGARICOCRINUS PLANOCONVEXUS, ACTINOCRINUS SCITULUS, PERIECHOCRINUS WHITEI.

FIG. 3.—Burlington section, Morning Sun, Iowa.

in the south bluff of English River, ¼ mile upstream from the highway bridge at Kalona, Iowa. A small quarry has exposed the *Pentremites* zone and the uppermost ledge of the *Dizygocrinus* zone. The characteristic faunas of both these zones are represented.

The Burlington limestone is unconformable on the underlying formations in northeastern Missouri and Iowa. In the region around Hannibal, Missouri, it lies on various formations. It may be seen in contact with the Sedalia limestone, the Choteau limestone, and locally the Hannibal shale. Where the Sedalia limestone occurs it is found to have been deposited in troughs eroded in the Kinderhook surface. The fact that Burlington beds lie directly on Hannibal shale in some places

suggests post-Sedalia, pre-Burlington erosion. In Iowa, the Burlington lies on the Wassonville member of the Hampton formation. Careful tracing of zones within the Wassonville shows that the Burlington lies on different parts of the member in different places. In general, the Burlington is in contact with successively younger horizons of the Hampton formation extending northwestward in Iowa.

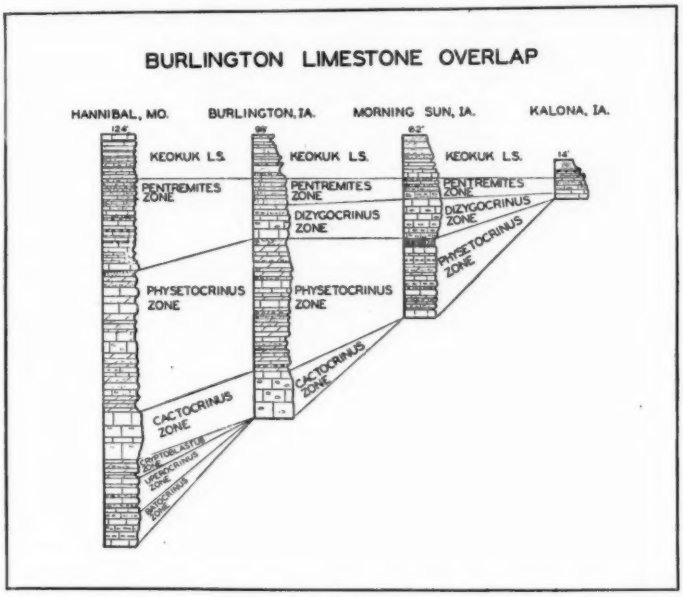

FIG. 4.—Cross section from Hannibal, Missouri, to Kalona, Iowa.

The Burlington transgressively overlaps against the underlying surface toward the north and west. The three lower zones of the Hannibal section are not present in the type section at Burlington.

At Burlington the *Cactocrinus* zone is in contact with Hampton beds. Northward from Burlington, each of the lower Burlington zones successively pinches out until the middle *Physetocrinus* zone is in contact with the Hampton in the vicinity of Morning Sun, Iowa. Northwestward from Morning Sun the overlap is still apparent. At Kalona, the northernmost Burlington section, the uppermost bed of the *Dizygocrinus* zone is in contact with the Hampton.

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ULTIMATE PRECISION OF BAROMETRIC SURVEYING[1]

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ABSTRACT

By constructing two aneroid barometers which could be compared with an instrumental precision equivalent to 0.3 foot of elevation difference, it was possible to obtain a measure of the errors of barometric surveying which originate solely from atmospheric disturbances. It was found that in fairly level country, under average weather conditions, the contribution of atmospheric disturbance to the probable error of a single elevation observation is 0.96 foot when two aneroids are 3 miles apart. Practical applications and methods of carrying out elevation surveys are discussed.

INTRODUCTION

In gravimetric and seismic surveys it is necessary to determine elevations of the points at which observations are taken. This is often accomplished at the present time by ordinary surveying methods. The cost of elevation control in gravimetric prospecting, especially, may run as high as one third of the total cost. Although a number of oil companies are using commercial altimeters in connection with gravity work, the rapid improvement of spring gravimeters in recent years indicates that, if barometric surveying is to be retained, its accuracy should be pushed to its ultimate practical limit. An improvement in the precision of barometric surveying would also, no doubt, be welcomed by geologists.

With these ends in view, there were constructed at the Gulf Research and Development Company laboratories two experimental aneroid barometers of entirely new design. Particular stress was laid on sensitivity and precision, at the expense of portability and convenience of operation. It was felt that one reason for the poor performance of many commercial altimeters is the over-emphasis on portability in their design.

DESCRIPTION OF THE BAROMETER

Figure 1 shows the barometer set up, while the essential features of its construction can be seen on Figure 2. The top of the evacuated bellows *B* is fastened to the frame, while the bottom is attached to a lever *L* by means of a flexible ribbon *R*. The lever is connected to the frame by a pair of similar ligaments *P*. The main part of the torque exerted by the bellows about the axis of rotation of the lever *L* de-

[1] Manuscript received, May 3, 1937.

[2] Gulf Research and Development Company. The writer takes pleasure in acknowledging his indebtedness to R. D. Wyckoff, who directed the work, and to Paul D. Foote and E. A. Eckhardt for permission to publish this paper.

fined by the ligaments *P* is balanced by two concentric springs *S* and *s*. One of the springs is made of elinvar, the other of phosphor bronze. By changing the relative loading of these springs the instrument is compensated for temperature. The remainder of the torque is taken care of by the adjustable elinvar spring *A*. Its upper extremity is fastened to a nut *U* which can be made to run up or down on a micrometer screw *M*, thus changing the tension. The nut is prevented from turning by a guide. The angular position of the beam is detected by a

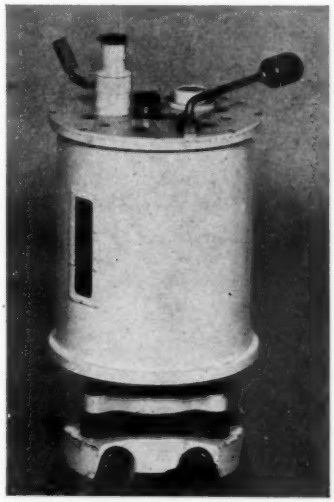

FIG. 1.—Barometer set up.

mirror *m* fastened to the lever, in conjunction with an objective lens and a gaussian eye-piece *E*. The tension of the adjustable spring is altered until the instrument is at standard deflection. The reading of the micrometer screw plus a constant is directly proportional to the air pressure. The instrument is mechanically damped by a small disc *D* plunged in a cup containing glycerin.

The angular sensitivity of the device to changes in air pressure can be adjusted by raising or lowering the point at which the ligament *R* is attached to the beam *L*. The sensitivity of the system is thus obtained in the same manner as in the gravimeter recently described by R. D. Wyckoff.[3]

[3] R. D. Wyckoff, "Earth Tides and Their Measurement," *Trans. Amer. Geophysical Union 17th Annual Meeting, 1936*, p. 47.

The aneroid system is enclosed in a tight can of considerable heat capacity connected to the atmosphere by a slow leak, which serves to average out rapid pressure fluctuations. The instrument is well heat-insulated by hair-felt and cork, which, together with its large heat capacity, assures small time-and space-temperature gradients. This feature is essential to good operation, because, due to the

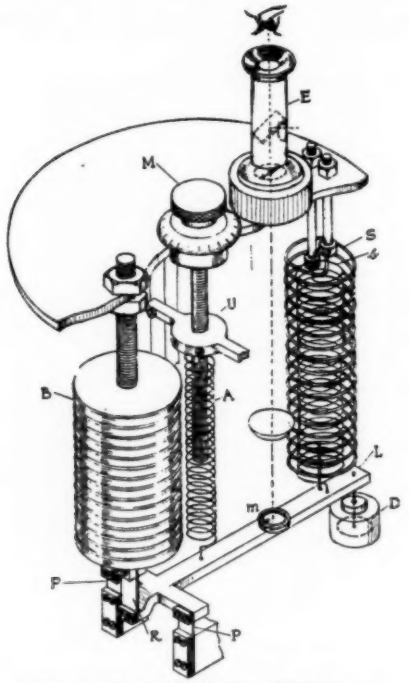

FIG. 2.—Schematic diagram of barometer system.

small hysteresis of thermal expansion and thermo-elastic changes in the materials, the two instruments drift with respect to each other when their temperature changes. This drift is regular and slow enough so that by comparing the readings of the two aneroids at the same spot every two or three hours, it can be eliminated with sufficient accuracy.

The micrometer screw has a range of 80 turns and is read to 1/100 turn. One turn is equivalent to about 20 feet of elevation, so that the instrument is read to 0.2 foot. This sensitivity and the absence of

sudden discontinuities arising from transportation shocks or other causes render the magnitude of errors of instrumental origin small in comparison with those due to atmospheric disturbances.

In the field the barometer is handled in much the same way as an Askania magnetic balance. It is carried on the front seat of the automobile, and care is taken to keep it right side up. It is set up on a light tripod and leveled to 1 minute of arc by means of a circular level.

The elevation difference between two geographic points can be computed by the ordinary hypsometric formula[4] from a knowledge of the pressure, temperature, and humidity at the two points. In the field work described in the following paragraphs, the pressures were measured simultaneously by two aneroids, while temperature and humidity readings were taken only by one operator and were assumed to be the same at both places. Furthermore, since the scale values of the barometers were accurately matched, it was found more convenient not to use the hypsometric formula but to multiply the difference of the pressure readings, as recorded from the micrometer screw dials, by a constant, and then to add a second order correction picked off from a specially computed table. This sum expressed in feet was then corrected in the customary manner for the temperature and humidity of the air column.

EXPERIMENTAL SURVEYS

Most gravimetric surveys are carried out in comparatively flat country. Such an area was picked out about 10 miles east of Youngstown, Ohio, for a test elevation survey. Figure 3 shows the topographic map of the region. On this map the encircled numbers refer to points at which elevations were measured. One barometer was kept stationary at base *B*, and was read every 2 minutes to determine accurate corrections for the time variations of the air pressure. The base operator also made frequent measurements of the temperature and humidity of the air. Three times in the course of the day the field operator returned to the base. This was sufficient to eliminate instrumental drift.

Tables I and II show the results obtained by this method of surveying. Table I gives the mean of the observed elevations in feet of stations 1 to 19 above base *B*. The mean observed elevation was assumed to be the true elevation of each station. The departures of the individual readings from the mean value are listed in Table II. As expected, the departures increase with increasing separation of the two barometers. The means of the absolute values of the departures for

[4] W. J. Humphreys, *Physics of the Air*, 2nd ed., p. 62.

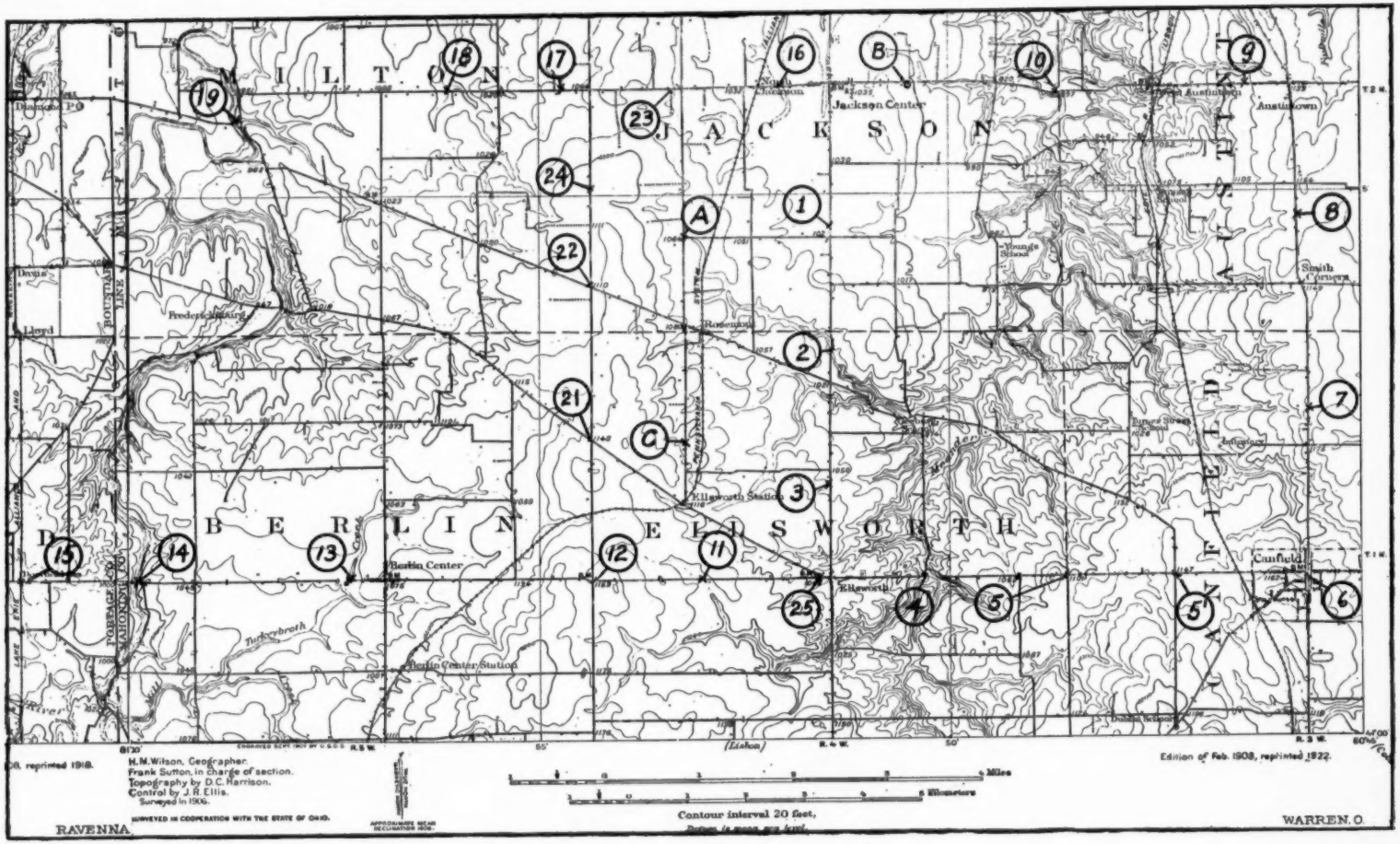

FIG. 3.—Experimental survey near Youngstown, Ohio.

TABLE I

MEAN ELEVATION IN FEET ABOVE STATION B (FIGURE 3)

Sta.	*Elev.*	*Sta.*	*Elev.*	*Sta.*	*Elev.*	*Sta.*	*Elev.*
1	19.0	6	155.6	11	110.3	16	10.4
2	13.3	7	157.1	12	154.5	17	35.2
3	52.1	8	141.7	13	42.6	18	−13.0
4	−39.3	9	102.1	14	− 17.3	19	−42.6
5	97.2	10	− 89.5	15	44.8		

stations at approximately the same distance from the base were multiplied by 0.845, and plotted in Figure 4 against the average separation

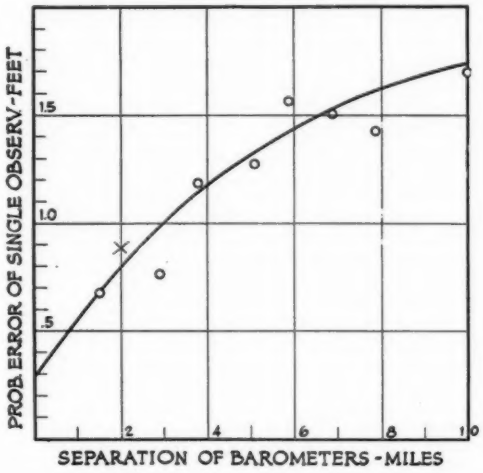

FIG. 4.—Dependence of probable error of a single observation upon separation of barometers.

from the base. From this curve one can obtain the probable error of a single observation for any station which may lie from 0 to 10 miles from the base. For example, the probable error of a station 3 miles away from the base is about 1 foot. This means that if a large number of observations were taken at this station, as many errors would be greater than 1 foot as would be smaller. To obtain the probable error of the mean of n observations, the probable error of a single observation is divided by $\sqrt{n}$. It must be kept in mind that the useful precision of a geophysical survey is at least three times the probable error. Thus, if the probable error is 1 foot, it is expected that one out of every 23 observations is in error by 3 feet or more. However, errors

TABLE II

DEPARTURES OF THE INDIVIDUAL OBSERVATIONS IN FEET FROM MEAN OBSERVED ELEVATIONS OF STATIONS 1 TO 19 ABOVE STATION B (FIGURE 3)

Sta. / Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
11–15	1.4	.1	−.1	.6	1.6	−3.8		−1.7	−1.9	−.3	−.5	−.5	−2.8	1.2	1.4				
35	−.4	−.8	1.7	.5	−2.6	−.4		−.7	−.9	−2.2	1.8	2.1	.4						
11–16	2.4	1.3	2.0	−1.1	3.2	3.0		1.7	1.2	.6	1.8	4.2	2.9	.4	−.3	−.4	.9	−.5	1.6
35	−.2	1.4									−.5	.4	1.1	2.9		0.0	3.3	1.5	2.4
11–17	−1.0	−.5	−.9	2.7	2.6	3.2	4.1	−2.3	−2.0	−2.2	2.7	−.2	1.2	2.4	3.7	−.1	−1.5	−.5	−2.1
35	−.3	.6	.7	.6	.1	.5	.9	1.3	−.1	−.6	1.8	.9	1.1	−.5		.3	−1.0	−.1	
				.3	−1.3	.3	.7	1.8	1.0	4.4									
11–18	−.9	−1.5	−1.8	−1.2	−1.6	−.5	−1.9	−.6	1.2	.7	−3.7	−3.9	−1.8	−2.3	−4.9	.3	−2.3	−.6	−2.0
35	−.6	−.5	−1.9	−2.6	−2.3	−2.4	−3.6	.7	1.5	−.4	−3.3	−3.3	−2.2	−4.0		0.0	.3	.4	
Mean Abs. Val.	.90	.84	1.30	1.20	1.91	1.76	2.24	1.35	1.22	1.42	2.01	1.94	1.69	1.71	2.58	.18	1.55	.60	2.02
Mi. to Sta. B	1.7	2.9	4.2	5.2	5.4	6.7	5.4	4.4	3.6	1.6	5.6	6.2	7.9	9.6	10.7	1.3	3.7	4.9	7.1

equal to or greater than 4 feet are expected to occur with the frequency of only 1 in 143 observations.

The contribution of instrumental errors to the probable error of the altitude measurements appears on Figure 4 as the intercept of the curve with the vertical coördinate axis. It is equal to about 0.3 foot.

A few experiments indicated that under disturbed atmospheric conditions large errors occur when the barometers are only 4 miles apart. Accordingly, a scheme of operation in which the barometers were never separated by a distance greater than the station spacing (1–2 miles) was tried out. Referring again to the station numbers on Figure 3, the base instrument was placed, for example, at station 2, while the field instrument took a "back-sight" on station 1 and a "foresight" on station 3. Then the base barometer was moved to station 4, and stations 3 and 5 were observed with the field instrument. In this manner the loop *B* 4 6 9 *B* was observed on 4 days.

A considerable disadvantage of this method is that only one reading is taken at the reference points. In the actual case the readings at station 6, a United States Geological Survey bench mark, fixed the absolute values of all the stations in the circuit. The error in this reading is thus added to the value of each station. In Table III the elevations were so adjusted that the mean of station 6 for 2 days was 1,161.0. September 19 and 21 were characterized by strong winds (about 30 mi./hr.), which shook the instrument enough to make reading difficult. Accordingly, these days were grouped together in Table III. The last row of Table III gives the elevations of the same stations from the means of Table I.

The circuit 16 17 12 25 16 was run on 2 days. The values are given in Table IV.

Another experimental survey was carried out near Saxonburg, Pennsylvania. Figure 5 shows the topographic map of the region with the locations of the stations. Stations 1–13 were observed with respect to base *A*, while stations 14–23 and also 10, 11, and 12 were referred to base *B*. The readings at 10, 11, and 12 were thus used as ties between the two groups of points. Observations were made on 10 days. Tables V and VI list the mean values of the stations, while Tables VII and VIII give the departures from these means on individual days.

The 258 observations yielded a probable error of a single observation of 0.89 foot, the average distance from the base barometer being 2 miles. This number is plotted on Figure 4 as a cross.

The precision with which base *B* was established with respect to base *A* can be estimated from Table IX. The probable error of one day's determination obtained by averaging the differences of the read-

TABLE III

ELEVATIONS IN FEET ABOVE SEA-LEVEL FROM CLOSED CIRCUITS, ADJUSTED TO STATION 6 (U.S.G.S. B. M. 1,161, FIGURE 3)

Sta. / Date	B	1	2	3	4	5	5′	6	7	8	9	10	Error of Closure
11–19	1,006.0	1,024.7	1,017.4	1.055.3	968.6	1,102.4	1,144.7	1,160.5	1,159.4	1,148.8	1,111.5	920.5	.5
11–21	1,004.9	1,023.9	1,020.9	1,060.0	969.6	1,099.6	1,142.1	1,161.5	1,165.3	1,148.3	1,108.6	915.4	7.3
Ave.	1,005.5	1,024.3	1,019.2	1,057.2	969.1	1,101.0	1,143.4	1,161.0	1,161.4	1,147.3	1,107.6	915.9	
11–20	1,008.3	1,025.0	1,017.9	1,056.3	964.0	1,101.8	1,146.2	1,159.8	1,163.3	1,149.1	1,110.8	920.5	1.2
11–22	1,005.9	1,024.8	1,019.5	1,058.0	965.4	1,103.8	1,147.6	1,162.2	1,162.7	1,147.9	1,106.7	915.4	− 4.7
Ave.	1,007.1	1,024.9	1,018.7	1,057.2	964.7	1,102.8	1,146.9	1,161.0	1,163.0	1,148.5	1,108.3	915.9	
Mean	1,006.3	1,024.6	1,018.9	1,057.2	966.9	1,101.9	1,145.1	1,161.0	1,162.2	1,147.9	1,108. 0	915.9	
From Table I	1,005.4	1,024.4	1,018.7	1,057.5	966.1	1,102.6		1,161.0	1,162.5	1,147.1	1,107.5	915.9	

Probable error of mean of two observations computed from "Ave." = 0.78 feet.

TABLE IV

ELEVATION ABOVE SEA-LEVEL FROM CLOSED CIRCUITS (FIGURE 3)

Sta. / Date	16	23	17	24	22	21	12 B. M. 1,159	11	25	3	2	1	Error of Closure
11–20	1,015.8*		1,040.2		1,109.6	1,148.4	1,156.8	1,113.7		1,057.5*			2.1
11–22	1,016.4	1,062.5	1,039.9	1,105.9	1,108.4	1,147.9	1,157.7	1,114.9	1,157.7	1,057.4*	1,019.3*	1,023.9*	−6.1
From Table I	1,015.8		1,040.6				1,159.9	1,115.7		1,057.5	1,018.7	1,024.4	

* Indicates stations used to tie elevations to station 6 (U.S.G.S. B.M. 1,161).

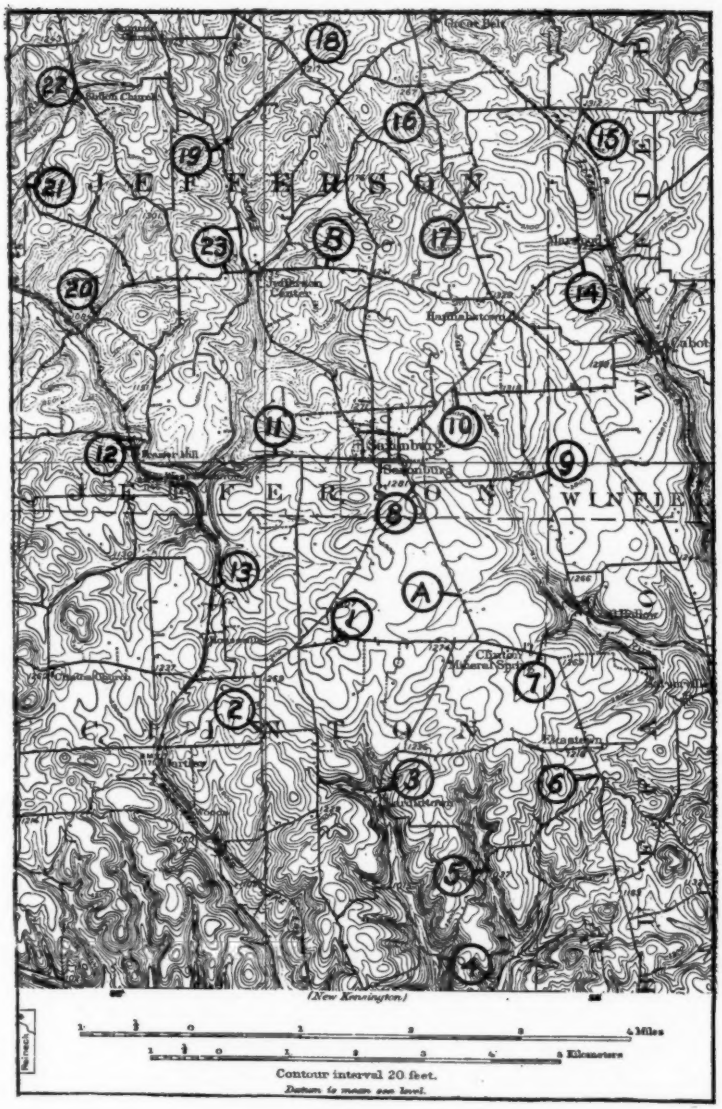

FIG. 5.—Experimental survey near Saxonburg, Pennsylvania.

TABLE V

MEAN OBSERVED ELEVATIONS IN FEET ABOVE STATION A (FIGURE 5)

Sta.	*Elev.*	*Sta.*	*Elev.*	*Sta.*	*Elev.*	*Sta.*	*Elev.*
1	74.8	4	−279.7	7	2.0	10	43.6
2	34.5	5	−200.6	8	33.4	11	− 66.8
3	−161.3	6	− 56.8	9	13.5	12	−193.5
						13	− 73.1

TABLE VI

MEAN OBSERVED ELEVATIONS IN FEET ABOVE STATION B (FIGURE 5)

Sta.	*Elev.*	*Sta.*	*Elev.*	*Sta.*	*Elev.*	*Sta.*	*Elev.*
10	23.1	14	30.2	17	76.4	20	−178.9
11	− 86.3	15	50.5	18	−49.6	21	− 28.5
12	−214.8	16	3.9	19	−73.5	22	− 54.4
						23	− 71.4

ings at the stations common to both groups is 0.75 foot. This quantity can be computed independently from the probable error of a single observation. The probable error of each difference in the middle columns of Table IX is $\sqrt{2}\times(.89)^2=1.02$ foot. Since there are 3 such differences $1.02/\sqrt{3}=0.72$ foot is the probable error of the mean. Although this volume of data is admittedly scanty for purposes of statistical analysis, it nevertheless does indicate that for that particular survey it is permissible to consider each observation at a common station as being independent from the readings at the other two stations taken on the same day. It is conceivable that by establishing a network of subsidiary bases, and then filling in stations around them as centers, a considerable area could be surveyed at low cost without accumulating large errors.

DISCUSSION OF RESULTS

The errors in barometric elevations may be due to random pressure fluctuations, to regional pressure gradients, and to instrumental inaccuracies. The contribution of the last to the probable error of a single observation was determined from Figure 4 to be 0.3 foot. If regional pressure gradients were responsible for some of the errors of atmospheric origin, they could be recognized because the magnitude and sign of the deviations would have a definite geographical distribution. It is evident that a study of systematic departures of this sort can be made only when data from a greater number of days are available. However, an attempt has been made to correlate the departures on individual days with pressure gradients scaled from weather maps. It was found that although in isolated instances beneficial corrections could be applied, the results as a whole were not significantly im-

TABLE VII

INDIVIDUAL DEPARTURES IN FEET FROM MEAN OBSERVED ELEVATIONS ABOVE STATION A (FIGURE 5)
DATES REFER TO JUNE, 1936

Date \ Sta.	1	2	3	4	5	6	7	8	9	10	11	12	13
8	−.8	−.8	−1.6	−.7	−.8	−1.1	−.3	0	.8	.5	2.1	1.3	−.5
9	.9	−.2	.3	.5	2.2	.8	−.9	.1	−.8	.2	.6	−.9	−.8
10	0	2.3	.1	.2	−.6	−1.7	.6	2.2	.6	−.2	−.8	.5	.1
11	−.4	−1.3	−.2	−.3	.4	1.7	2.2	−.8	.4	−1.0	−3.7	.6	1.7
12	−.1	1.2	1.2	2.0	.8	.7	.1	−2.0	−.9	.4	−1.0	−1.2	−.9
15	−.4	.2	−.5	−1.3	1.4	.5	−.6	−1.4	−.8	−1.2	.7	0	−2.9
16	−1.1	−.2	−.9	−.5	.3	1.8	1.7	.5	2.5	−.8	−.5	−3.3	−2.4
17			1.4	−1.6	−1.4	−1.0	0	2.0	−1.3	2.3	2.3		4.2
18	.5	2.1	−.3	1.2	−.5	.6	−2.2	.8	−2.0	−1.0	−.6		2.6
19	−.3 1.9	−2.3 −.8	.8	.4	−1.8	−2.0	−.7	−1.5	1.3	.9	.5	−.9 3.8	.5 −1.4
Mean Abs. Value	.64	1.14	.73	.87	1.02	1.19	.93	1.13	1.14	.85	1.28	1.39	1.64

TABLE VIII

INDIVIDUAL DEPARTURES IN FEET FROM MEAN OBSERVED ELEVATIONS ABOVE STATION B (FIGURE 5)
DATES REFER TO JUNE, 1936

Date \ Sta.	10	11	12	14	15	16	17	18	19	20	21	22	23
8	−1.4				.9	−1.5	−.8						
9	.1	.1	−.7	−1.5	1.0	−.9	−.4	.8	−.4	−.7	−.9	−.4	−1.1
10	1.2	−1.5	−1.1	.9	.1	.5	2.4	2.6	2.1	.1	2.4	1.0	.8
11	.3			1.9		2.3	3.8						
12	−.5	.8 −.4	.6 −.3	−1.2	−.1	−.5	−.8 −1.1	−1.3 0	−1.0 0	1.1 −.3	−.5 .9	0	−.1 .8
15	−1.0	−1.0 −.1	1.3 1.0	1.8	2.3	−1.1	−1.4 −1.5	.1 −1.1	.7 −2.0	.6 −1.7	−.7 −.8	−.3 −.1	.6 −.5
16	.9	−.5	−1.2	−1.5	−2.3	.8	1.1	.8	3.8	−1.8		−1.0	−.8
17	−.6	−1.3	−1.0	−1.4	−1.5	1.2	−.4	−2.5	−1.1	.2	1.2	.6	.9
18	−.3	2.6	.9	1.3	−.7	−1.1	.2	.7	−1.0	−.7	−3.7	2.0	−1.1
19	1.1	1.2	.5	.1	.8	.4	−1.0	.4	−.8	3.2	2.4	−1.3	.6
Mean Abs. Value	.74	.95	.86	1.29	1.02	1.03	1.24	1.03	1.29	1.04	1.50	.74	.73

TABLE IX

OBSERVED ELEVATION IN FEET OF BASE B ABOVE BASE A (FIGURE 5)

Date \ *Sta.*	*10*	*11*	*12*	*Average*
June 8 '36	22.4	21.7*	21.6*	21.9
9	20.6	20.0	21.1	20.6
10	19.1	20.2	22.9	20.7
11	19.2	16.2*	22.2*	19.2
12	21.4	17.7	19.5	19.6
15	20.3	21.2	20.0	20.5
16	18.8	19.5	19.2	19.2
17	23.4	23.1	22.3*	22.9
18	19.5	16.3	24.2*	20.0
19	20.3	18.8	19.9	19.7
Mean				20.4

Probable error on one day's determination = 0.75 foot

* Observation taken on another date.

proved. It may, therefore, be concluded that the errors of atmospheric origin in the experimental work here outlined are due to pressure fluctuations of random character, and can not be calculated from general meteorological data.

From *a priori* considerations, however, it is conceivable that in regions where strong prevailing winds exist, systematic discrepancies would occur in barometric surveying. In such regions, barometers could still be used to measure the elevations of stations located between two parallel lines about 20 miles apart surveyed by level. Starting at a known elevation on one line, the barometer would travel normally to it until it reached a known elevation on the other surveyed line. The accumulated error of closure due to a constant atmospheric pressure gradient could then be distributed among the intermediate barometer stations.

CONCLUSIONS

Although the volume of data presented here is not very great, it is sufficient to demonstrate that under average weather conditions and with a separation of 3 miles, the contribution of atmospheric disturbances to the probable error of a single observation is only 0.96 foot. Our experience shows that it is not very difficult to devise a barometric system which performs with a precision more than 3 times as great. As a matter of fact, only one scheme was tried, and only two instruments were built. It is hoped that in the near future an enterprising instrument firm will develop the sensitive and dependable aneroid so badly needed now in petroleum geophysics.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 9 (SEPTEMBER, 1937), PP. 1182-1192, 1 FIG.

STRATIGRAPHIC COMPARISON OF POLISH CRUDE OILS[1]

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ABSTRACT

An approximate, comparative classification of crude oils is given by stratigraphic horizons and depths of occurrences in the Polish fields. Differentiations of crude oils can not be explained unless the heterogeneous character of the primary organic substances is considered.

A comparative compilation of material pertaining to oil fields in various countries compels taking a critical attitude towards some theses widely propagated in petroleum geology.

Seemingly "revelatory" discoveries of Russian scientists, concerning biochemical accidents of the Black Sea, failed to give anything new as regards the part of biochemical factors in the formation of fluid crude oil. Conclusions drawn from McKenzie Taylor's investigations can not be taken to deny the tremendous influence exercised by chemical reactions in the process of formation and evolution of coal and crude oil in the course of geologic time.

Sediments may presumably be sapropellites of the type found at the bottom of the Black Sea; however, it would be unjustified exaggeration to look for source beds solely among analogies with the bottom of that sea.

Investigations by Hackford, Berl, Treibs, Haseman, and others, abolish the principal argument against the possibility of crude oil originating not only from vegetable and animal plankton, but also from humic products from the cellulose of green plants, as has been, in its time (1918), inferred by the late R. Zuber, senior, on the basis of geologic observations.

The extreme conception of the principal cause of crude oil accumulating in reservoirs exclusively or principally through deformation of unconsolidated sediments and of consolidated sediments at the time of folding or finally by vertical migration—such a conception fails to take into consideration other accidents that lead to reservoirs becoming closed, nor does it take into account actual geologic material concerning oil fields.

[1] This article is the author's English summary of his article "Niektore Zagadnienia geologii Ropnych Zloza" (Some Problems of Petroleum Geology) published in the *12th Annual of the Geological Society of Poland* (1936), pp. 487–568.

Reprinted by permission of the author. The Polish volume, *Rocznik Polskiego Towarzystwa Geologicznego*, Tom XII (Krakow, 1936), is dedicated to Professor Bohdanowicz to celebrate the fiftieth anniversary of his scientific activity. [Editor.]

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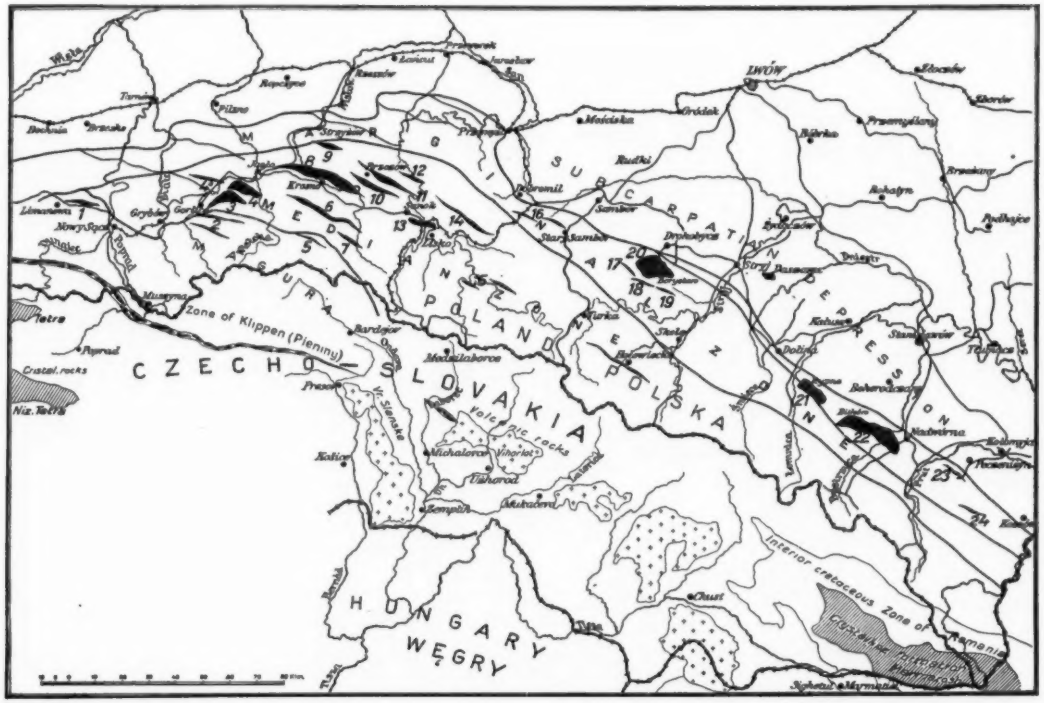

FIG. 1.—Oil fields of Polish Carpathian Mountains. *1*. Klęczany. *2*. Ropa-Szymbark-Siary-Męcina-Ropica. *3*. Dominikowice-Kobylanka-Libusza-Kryg. *4*. Harklowa-Wójtowa. *4a*. Biecz-Załawie-(Korczyna). *5*. Ropianka-Smereczna-Wilsznia-Komornik (Czechoslovakia). *6*. Bóbrka-Wietrzno-Równe-Rogi. *7*. Rudawka Rymanowska-Tokarnia-Wola Sękowa. *8*. Sądkowa-Białkówka-Brzezówka-Męcinka-Jaszczew (gas fields) and Potok-Toroszówka-Krosno-Krościenko-Trześniów (oil fields). *9*. Węglówka. *10*. Zmiennica-Turzepole-Strachocina. *11*. Starawieś-Brzozów-Humniska-Grabownica. *12*. Izdebki-Witryłów. *13*. Zagórz and vicinity. *14*. Stańkowa-Paszowa-Ropienka-Wańkowa-Leszczowate. *15*. Rajskie-Polana and vicinity. *16*. Starzawa-Stara Sól-Strzelbice. *17*. Opaka. *18*. Schodnica. *19*. Pereprostyna-Urycz. *20*. Borysław-Tustanowice-Mrażnica. *21*. Rypne-Duba-Perehińsko. *22*. Majdan-Rosulna-Bitków-Pasieczna. *23*. Sloboda Rungurska. *24*. Kosmacz.

Map shows three tectonic zones each overthrust northeast toward sub-Carpathian depression (foreland): (1) Magura (not oil-bearing excepting in tectonic inliers), (2) Median (oil in Cretaceous-Oligocene), (3) Marginal (oil in Cretaceous-Oligocene). In sub-Carpathian depression gas is produced from Miocene. East-west length of area mapped, approximately 236 miles.

Map from Charles Bohdanowicz, "Oil Fields of Poland, Geological and Statistical Summary," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 9 (September, 1933), Fig. 1, p. 1084.

Coördinated investigations of geologic conditions of crude oil deposits and of peculiarities displayed by crudes, will lead to the conclusion that differentiations of crude oil can not be explained unless the heterogeneous character of the primary organic substance is taken into consideration.

In spite of divergent opinions advanced by modern geologists as regards the part played by various factors in the formation of individual peculiarities of crude oils, the hypothesis may be risked that there are no general laws that would seemingly prejudicate the uniformity of the primary organic substance, a generally uniform process of crude oil accumulation in deposits, or a generally uniform direction of evolution of crude oil. Negation of such general laws arises from knowledge of crudes and of crude oil deposits becoming more and more profound.

The complex of coördinate investigations in petroleum geology and engineering, must, conforming to the ideas of the late D. White, become the object of research work by institutes broadly organized and correspondingly equipped as regards both means and men.

CHARACTERS OF POLISH CRUDES

Available material covering present characters of Polish crudes[3] makes possible only an attempt at an approximate comparative classification of crudes by stratigraphic horizons and depths of occurrences in the various oil fields of this country.

OLIGOCENE

KROSNO SERIES

Field	*Depth Meters*	*Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
Harklowa	371	0.896	—	—
	442	0.897	0.8	—
	446	0.894	0.8	—
	450	0.894	0.8	—
	532	0.902	0.9	—
Mokre	367	0.808	0.3	—
	550	0.813	0.3	—

[3] K. Tołwiński, "Złoża ropy i wody podziemne Borysławia" (Les Gisements pétrolifères et les Eaux souterraines de Borysław). Analytics Dr. Doliński, *Biul. of the Geol. Station* (1922), 5.

Ch. Bohdanowicz, "Lettres de Pologne," *La Revue Pétrolifère* (1926), 194.

K. Bohdanowicz, *Geologia Naftowa* (Petroleum Geology) (1931), pp. 30–32.

A. Szayna i J. Ehrlich, "Analizy Rop Małopolskich" (Analyses of Galicia Crudes), *Przem. Nafl.* (1932), 1–6.

J. Ehrlich, "Analizy Rop Małopolskich" (Analyses of Galicia Crudes), *Przem. Naft.* (1934), 18–24.

K. Katz, "Analizy Rop Polskich" (Analyses of Polish Crudes), *Karp. Inst. Geol. Naft.* (1936), 25; *Geol. i Stat. Naft. Polski* (Géologie et Statistique du Pétrole en Pologne) (1932), 3.

A series of papers by Prof. Arctowski of the Institute for Geophysics and Meteorology, Univ. Lwów (1928–1933).

Tarnawa Dolna	700	0.850	0.5	−
Rajskie	382	0.805–0.834	5.1	+
	432.2	0.821	0.8	−
	509.4	0.818	0.7	−
Bystre	180	0.806	0.4	−
Lipie	±200	0.893		−

Asphalt base (non-paraffine) crudes, both light and heavy, display a trend showing higher specific gravity with increased depth. There is no particular information regarding paraffine-base crude occurring above the asphalt-base crude in shallow horizons at Rajskie.

In the oblong fold, overthrown toward the south between Lodyna and Stańkowa, there are two crude oil horizons: (1) the upper one in

SERIES OF MENILITE SLATES AND THEIR UPPER CONTACT

Field	*Depth Meters*	*Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
Lodyna	300	0.8356	1.23	−
Leszczowate	530	0.844	5.8	+
	546	0.858	5.6	+
Brelików	261.7	0.8495	3.9	+
	422.85	0.8628	4.5	+
Wańkowa	315	0.8501	3.6	+
	466	0.863	3.5	+
	535	0.870	2.3	+
	595	0.872	2.4	+
(Eocene)	800	0.844	5.7	+
Ropienka	206	0.8594	1.2	−
	215	0.871	0.9	−
	305	0.851	4.1	+
	332	0.831	5.0	+
	340	0.8492	5.3	+
	374	0.846	5.9	+
Paszowa	196	0.831	0.5	−
	330	0.844	0.7	−
Stańkowa	208	0.858	0.8	−
	292	0.865		−

formations grading into the Krosno series and containing a light asphalt base crude, in Ropienka a heavier one; (2) the lower horizon in the upper strata of the Menilite series carrying a heavier paraffine-base crude, some of it only slightly paraffinic, with a tendency to decrease the paraffine content with increasing depth while synchronously increasing the specific gravity. The third incidental crude oil horizon found in Wańkowa, occurs in the Eocene and holds a light crude having a larger paraffine content.

Field	*Depth Meters*	*Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
Wołosianka Mała	105	0.863	0.7	−
	206	0.838	7.5	+
Rypne	519	0.831	4.6	+
	638.5	0.844	6.7	+
	855.5	0.859	5.2	+
Duba	846.3	0.841	8.0	+
Bitków	860.5	0.795	3.1	+
	960	0.767	1.1	+

Bitków	995.3	0.839	7.1	+
	1,000	0.834	6.5	+
	1,017.5	0.852	8.4	+
	1,078	0.818	3.8	+
	1,097.7	0.833	7.1	+
	1,212.9	0.786	2.0	+
	1,309.5	0.821	3.4	+
	1,324	0.824		
	1,497	0.830		
Pasieczna				
Maurycy	930.5	0.755	0.2	−
	1,118	0.838	4.9	+
	1,129	0.811	2.3	+
Chrobry 1	1,162	0.811		+
	1,285.7	0.822	3.8	+
Laszcz	1,500	0.793		+

Those crudes are light and slightly paraffinic. The increase of paraffine is accompanied by increased specific gravity. With increased depth, the quantity of gasoline fractions in the crudes becomes less, which may result from the action of edge water (Bohdanowicz, *Geol. Naft.*, p. 32), while the specific gravity of the crude increases; an exception constitutes the crude from the Maurycy well, the only one in Bitków and Pasieczna that has asphalt base. Light crudes can not be observed to be dependent on the degree of tectonical tension in the uplifted portions of the fold, as is assumed by Katz (wells Stefan No. 2 and T. P. G. No. 1 in Pasieczna), while the wells Laszcz 1 and Chrobry 1 would deny this admission. Pressure at greater depth would under normal conditions, and except for the influence of edge water, result in light hydrocarbons becoming dissolved and the specific gravity less, as is the case in Laszcz well No. 1.

In the overthrust the crude oil occurs in the Cretaceous series and it belongs to the light asphalt-base and slightly paraffinic classes.

Field	*Depth Meters*	*Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
Pasieczna	306	0.791	0.5	−
	333	0.769	0.3	−
	378.8	0.730		
	479.3	0.786	1.6	+
	489.6	0.771	0.7	−
	512.5	0.776	0.7	−
Bitków	392	0.728		−

EOCENE

Field	*Depth Meters*	*Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
a) Biecz	151.5	0.829	0.4	−
	240	0.831	0.3	
	343.6	0.817	1.1	±
Lipinki	141.3	0.857	5.9	+
	214	0.862	6.0	+
	412–500	0.861	7.4–4.5	+
	550	0.834	8.4	+
Libusza	200–300	0.855	3.0	+
Potok	573	0.827	0.4	−

Potok	720	0.826	0.4	−
	734	0.822	0.2	−
	1,050	0.840	0.37	−
Dobrucowa (Męcinka)	975.1	0.813	4.0	+
Toroszówka	160–250	0.775–0.790		−
Krościenko Niżne	443	0.884	0.7	−
	518	0.882	0.35	−
Krościenko Wyżne	624	0.858	8.0	+
Turzepole	676.1	0.861	6.7	+
Stara Wieś	305	0.796	4.0	+
	336	0.797	3.8	+
Brozozów	400	0.805		

Crudes occur in the various folds: in the Lipinki-Libusza-Dominikowice fold the crudes from Ciężkowice sandstones are exclusively paraffine base and rather heavy, while those from the fold of Biecz and Potok-Krościenko are almost exclusively asphalt base. Paraffine-base crudes occur in parallel folds lying farther north (Turzepole and Brzozów); and on the extension of the Brzozów fold, in Humniska and Grabownica, crude oil horizons occur in the Cretaceous, both asphalt base and paraffine base.

Field	*Depth Meters*	*Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
b) Kobylany	300–400	0.867	7	+
Wietrzno	535	0.834	0.5	−
Bóbrka	420	0.857	0.7	−
	450	0.862	2.6	+
Równe-Rogi	608.9	0.840	0.8	−
	650.4	0.861	5.8	+
	1,132	0.855–0.814	6.2	+
Lubatówka	698.5	0.845	0.3	−
Iwonicz	380–400	0.920–0.950	?	+
	470–500	0.780–0.796		−
	500–647	0.820–0.840		−

Those crudes occur in various parts of the same fold, consisting of Eocene formations. The light asphalt-base crudes come from upper horizons which are tapped at various depths between 420 and 700 meters, depending on the plunge of the fold's axis, while the heavier paraffine-base crudes come from the lower horizons (the IV sandstone in Bóbrka may be Cretaceous). Regarding the heavy paraffine-base crudes in Kobylany and Iwonicz, found above the asphalt-base crude, we have no particulars.

Field	*Depth Meters*	*Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
c) Majdan	203.5	0.839	0.8	−
	402	0.881	1.1	−
Starunia	636	0.830	5.9	+
	785.5	0.854	9.8	+

In those fields may be observed a tendency of both asphalt and paraffine crudes to increase specific gravity along with depth, which

phenomenon may also be observed in the fields in the groups *a* and *b*, independently of the character of the crudes.

CRETACEOUS FORMATIONS

	Field	*Depth Meters*	*Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
a)	Magura facies, Klęczany (southern portion)	250	0.809	4.6	∓
		280	0.811	4.6	+
		300	0.808	4.6	+
	Klęczany (northern portion)	?	0.885		+
	Szymbark	?	0.826	slightly paraffinic	+
	Sękowa	150–200	0.839–0.880		−
	Męcina Wielka	186	0.848	0.4	−
	Ropianka (Dukla)	132	0.883	0.4	−
		370	0.872	0.4	−
b)	Węglówka	121.5	0.879	0.4	−
		169.7	0.879	0.4	−
		275	0.894	0.5	−
		450	0.875	0.4	−
		566.8	0.881	0.4	−
		?	0.884		+
	Grabownica	459	0.829	0.3	−
		564	0.822	0.2	−
		943–1,000	0.830	0.7	−
	Humniska	400– 500	0.825		−
		700–1,000	0.839	5.9	+
	Strzelbice (Jamna sandstone)	150– 200	0.862–0.872		+
c)	Kropiwnik	192	0.806	0.3	−
	Schodnica (*Inoceramus* beds)	811.5	0.829	5.9	+
	Kosmacz	526	0.875	0.8	−
		533	0.867	0.9	−
		625	0.879	0.9	−
		629.5	0.861	1.1	−
		646	0.870	0.9	−
		664	0.865	1.1	−
		782	0.870	0.9	−
	Słoboda Rungurska (Jamna sandstones)	164	0.850		+
		235	0.838	5.3	+
		245	0.840	5.2	+
		250	0.840	5.9	+
		311	0.839		+

Among the Cretaceous crudes, the asphalt-base type predominates distinctly, the light type in the formations of the Magura facies and in the core of the Eocene fold of Grabownica; in Humniska at 150 meters below the last asphalt-base horizon there occurs a horizon of heavier paraffine-base crude, similar to that in Bóbrka (in the Eocene horizon). In Węglówka and in Kosmacz the asphalt-base crudes are heavy. Crude coming from the Jamna sandstones is paraffine base and shows medium specific gravity. In the overthrust parts in the

Pasieczna fields, the crudes are, as has been stated before, asphalt base, and are lightest of all Cretaceous crudes.

Most Productive Fields

A. SCHODNICA—URYCZ—OPAKA

The principal crude oil horizon occurs at the upper contact of the Jamna sandstone and in that sandstone itself. There are but few data concerning crudes from Eocene sandstones; to this horizon belong the crudes of Opaka and some shallow crudes of Schodnica and Urycz.

Field	*Depth Meters*	*Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
Opaka—Lower Eocene	300	0.808	5.4	+
	640	0.817	6.1	+
Schodnica—Eocene	302	0.823	3.6	+
	352	0.827	1.6	−
	360	0.829	3.6	+
—Jamna	419	0.847	0.9	−
	452	0.871	0.7	−
Inoceramus-Cretaceous formations	811.5	0.829	5.9	+
Urycz—Eocene	165.2	0.882	0.4	−
	189.7	0.872	0.3	−
—Jamna	355	0.872	0.5	−
	386	0.872	0.4	−

The crudes coming from the Lower Eocene are light paraffine, grading into slight paraffine crudes. Those from the Jamna sandstones are rather heavy asphalt base, and those from the Cretaceous, light paraffine. In Urycz all crudes are asphalt base and rather heavy. The crudes from Jamna sandstones and from the Lower Eocene constitute one group, even though the paraffine content increases upwards. In Schodnica, on the other hand, there is observed at the same time plainly a tendency of specific gravity becoming less in the upward direction. Crudes from Jamna horizons on the Schodnica-Urycz fields show characters different from crudes from the same horizon in Sloboda-Rungurska.

B. BORYSLAW—MRAŻNICA—TUSTANOWICE

The deep fold has a normal stratigraphic structure.

	Range of Depth (Meters)	*Average Sp. Gr.*	*Paraffine Content*	*Residue Cold Test*
Palonica beds	1,000–1,250	0.863	9	+
Menilite series	1,300–1,700	0.859	8.9	+
Borysław sandstone	1,300–1,600	0.855	8.5	+
Eocene	1,250–1,600	0.862	8.9	+
	According to other analyses up to 1922, Eocene crudes at depths ranging from 1,300 to 1,500 meters averaged less specific gravity, that is, 0.852.			
Jamna sandstone	1,500–1,600	0.863	8.4	+
	According to other analyses up to 1922 crude oils from sandstones of these series and found at depths ranging from 1,450 to 1,560 meters had specific gravity of 0.850 or even less.			

OVERTHRUST				
a) Jamna sandstone and upper part of *Inoceramus* beds (same as in Orów)	164– 176	0.882	0.8	–
b) Jamna sandstones in border slide, deeper horizon	428– 500	0.873	6	+
c) *Inoceramus* beds				
1) Shallow level	300–1,000	0.848	7	+
2) Deeper level in bottom parts of overthrust	1,000–1,700	0.861	9.4	+

In the overthrust, besides the heavy minus crude coming from the shallow beds of the Jamna sandstone and the *Inoceramus*, all crudes belong to the heavy paraffine class, displaying a tendency to show higher specific gravity with increasing depth, with the paraffine content increasing collaterally (from 7 to 9.4 per cent). In the deep recumbent fold, Polanica crude shows indications of the influence of water: an abnormal increase of specific gravity and of the paraffine content. From the Menilite series on to the Jamna series inclusive it can not be observed whether the specific gravity of crudes increases or decreases, the paraffine content being stable. It may be supposed that the lesser specific gravity of the crudes from the Menilite series and from the Boryslaw sandstone may result from a larger quantity of gas being found in those series than in the lower ones, while the rather high specific gravity of the Eocene crudes and those from Jamna sandstones, that has been observed in recent years, may stand in connection with the crudes of those levels having degassed to a considerable extent, and with the increase in them of heavy paraffine compounds.

It may be assumed that as exploitation of crude oil horizons goes on, the degassing of crudes directly at the place of their occurrence and the influence of edge water or of water penetrating in some other way, will counteract the normal original conditions governing specific gravity. The abnormally high specific gravity of crudes from the Borysław sandstone in the wells Joffre No. 2 (0.865), Tryskaj (0.860), Zofja No. 1 (0.861), Mraznica-Nobel No. 12 (0.870) or Min. Kwiatkowski (0.870), Banzaj (0.868), is caused probably by the emulsifying effect of the surrounding edge water (brine).[4] This admission, however, would seem to disagree with observations made on the Bradford field

[4] The Eocene crudes from the Union field in Borysław-Mrażnica invite investigation, as that field is flooded from the north. According to Katz, Union well No. 6 has from the unflooded Borysław sandstone (1,387 m.), crude oil showing a specific gravity of 0.8566, while the Rela well (1,578 m.), situated directly beside the Union field, produces from the Lower Eocene a crude coming from the levels of 1,412 and 1,530 meters and having a specific gravity of 0.869 with 25 per cent impurity content.

in Pennsylvania, where the specific gravity of crude obtained by water flooding is 2° Bé. higher, that is, such crude oil is lighter than crude obtained by the common method of exploitation, while, on the contrary, the air-lift method tends to increase the specific gravity of crude, probably because an oxidation of hydrocarbons is taking place.[5] Methods of exploitation and the length of time during which they are applied influence the specific gravity of crudes.

General Comments

Crude oils from the various Polish oil pools belong to several different types.

1. Cretaceous, including the crudes from Jamna horizons, asphalt-base (non-paraffine) light and heavy, and, less commonly, semi-paraffine and light.

2. Eocene asphalt-base light, semi-paraffine and paraffine-base heavier.

3. In the series of Menilite shales are paraffine-base crudes and semi-paraffine, heavier and lighter; no non-paraffine crudes have been observed in this series.

4. The Krosno light asphalt-base crudes, with heavier ones being rather scarce.

5. From among the stratigraphic series just enumerated, the Menilite series displays the most uniform facial character, beginning at the fields of Libusza-Lipinki on the west as far as the Bitków region on the southeast, and it is just this series that generally contains crudes of the most uniform character.

6. Variation of the crudes belonging to about the same chemical type, as for example the non-paraffine crudes (Harklowa, Węglówka, Grabownica, Iwonicz, Równe, Rogi, Kosmacz), is based principally upon a different content of light gasoline and lubricating fractions, and this finds expression in the prices paid normally for those crudes, —the prices standing in an inverse ratio to the specific gravity of each particular crude.

7. In spite of a chemical variation of crudes belonging to the same stratigraphic series, there may be distinguished certain geochemical types of crudes within the confines of the Polish Carpathian petroliferous province.

8. In the cross section of the Borysław fields, the geologic series, except the strictly Menilite series exclusive of the Borysław sandstone, differ in their facial formation from the approximately synchronic

[5] Newby, Torrey, Fettke, and Panyity, "Bradford Oil Field," *Structure of Typical American Oil Fields*, Vol. II (1929), p. 433.

series found in larger areas of the western and eastern Polish Carpathians. The crudes from each series, as found at the Borysław field, show few differences from one another except crude coming from the shallow parts of the overthrust; however, they display a character different from that of crudes in synchronic formations. The crude from the shallow parts of the Cretaceous overthrust (series *a*) approaches the heavy Cretaceous crudes of Węglówka and Kosmacz.

9. Crude oil fields occur on tectonic structures which range from more or less normal folds (Potok, Równe, Rogi), and folds inclined at various angles, to folds entirely recumbent (Borysław). Those various shapes may be divided into two groups: (a) disharmonic foldings with extrusions of the deeper older formations compressed into diapiric uplifts (Potok, Grabownica, Stara Wieś, Bóbrka, Rogi), or such retaining the shape of more gentle folds (Lipinki, Węglówka); (b) disharmonic foldings with older formations thrust over younger (Borysław, Rypne, Bitków). In some cases both types may combine, as for instance in Harklowa.

10. The forms of group (b) are the expression of the highest degree of orogenic tension, and dependently on this condition deposits show the highest paraffine content (Borysław, Rypne, Bitków), and the primary character of various crudes has the greatest homogeneity (Borysław).

11. Variations in specific gravities of crudes—those having a paraffine base as well as those non-paraffinic—can not be subordinated to the "Dichteregel" by Krejči-Graf, especially if the changes in the specific gravity brought about by long exploitation periods are taken into consideration. For paraffine-base crudes it might be expected that with increasing depth the specific gravity would normally decrease, while reversely with non-paraffine crudes the specific gravity would under those conditions increase (Węglówka, Grabownica, Iwonicz), which would be contrary to "Dichteregel."

12. Non-paraffine crudes occurring in Grabownica and Bóbrka above those having a paraffine base might, if it were possible to prove their transitory character from paraffine-base crudes, furnish examples of asphalt "caps" resting on paraffine-base crudes; there are also cases of a reverse relation of paraffine crudes above non-paraffine crudes (Rajskie, Iwonicz, Schodnica).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 9 (SEPTEMBER, 1937), PP. 1193-1205, 3 FIGS.

GEOLOGIC SIGNIFICANCE OF A GEOTHERMAL GRADIENT CURVE[1]

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ABSTRACT

The Getty-Dooley well No. 7 was drilled in Eddy County, New Mexico, to a depth of 6,683 feet and passed through a thick section of Permian rocks, including the Rustler, Salado, Carlsbad, Capitan, Delaware Mountain, and into the top of the Bone Spring limestone. This stratigraphic section is divisible into three lithologic units: the Rustler-Salado, the Carlsbad-Capitan, and the Delaware Mountain unit. The subnormal geothermal-gradient curve for this well is also divisible into three parts and these subordinate gradients coincide with the lithologic divisions. Other possible factors that might cause the fundamental variations in the geothermal-gradient curve, such as water, heat reactions from solution, igneous intrusions, and radioactivity, are found wanting to explain the character of the curve. The radioactive heat of potassium is also found insufficient to affect the gradients in the Permian basin. It is therefore concluded that this subnormal geothermal-gradient curve owes its form to the different conductivities of the successive layers of rock.

INTRODUCTION

Temperature tests have shown that a subnormal temperature condition prevails in the Permian Basin,[3] though the cause for this anomaly is not definitely known. The suspension of drilling of a deep test for oil in the Getty pool in eastern Eddy County, New Mexico, recently afforded an opportunity to make a temperature test through a thick section of Permian rocks of different lithologic character. The writer acknowledges with appreciation his indebtedness to C. E. Van Orstrand for the well-temperature data and to H. C. Spicer for his computation by the method of least squares of smoothed reciprocal gradients for different depths. The depth-temperature readings were made by lowering thermometers into the well by means of a hand-operated reel and line. This method is less liable to inaccuracies than the use of the sand line and bailer. Also the hole was practically full of water, a condition that is more favorable to complete temperature adjustment than a dry hole.

LOCATION AND DEPTH OF WELL

This well, the George F. Getty Oil Company's Dooley No. 7, located in the S.W., N.W. ¼, Sec. 24, T. 20 S., R. 29 E., Eddy County,

[1] Manuscript received, June 24, 1937. Published by permission of the director, United States Geological Survey.

[2] United States Geological Survey.

[3] W. B. Lang, "Note on Temperature Gradients in the Permian Basin," *Jour. Wash. Acad. Sci.*, Vol. 20, No. 7 (1930), pp. 121–23.

New Mexico, (Fig. 1a) was drilled from the surface to 230 feet with standard tools, continued to 6,053 feet with rotary tools, and later completed to the present depth of 6,683 feet by a return to standard-tool equipment. The well remained idle for 5 months, after drilling was suspended, before temperature measurements were made. This lapse of time is sufficient for such temperature variations as may have been induced by the drilling of the well, to return to normal.

STRATIGRAPHY

The well penetrated sedimentary rocks of Permian age. The beds lie practically horizontal and have remained undisturbed by folding or faulting since their deposition. In fact, this region appears to have been one of marked stability since pre-Cambrian time. Some of the rocks of the section comprise an unusual reef structure with abrupt lateral sedimentary gradations.[4] This test was begun at the top of the Rustler formation, which is also the top of the Permian (Fig. 1b). The Rustler here rests, at a depth of approximately 360 feet, upon the Salado halite.[5] Beneath the Salado at 1,026 feet are the Carlsbad and Capitan limestones, the reef limestones. This limestone section continues to a depth of 3,823 feet, at which point the Delaware Mountain facies appears. These sandstones continue with minor black shale breaks to 6,266 feet, where they rest on the Bone Spring limestone.

The section comprises four lithologic units: (1) the Rustler and Salado unit, composed of red beds, halite, anhydrite, gypsum, sandstone, dolomitic limestone, *et cetera*; (2) the Carlsbad and Capitan unit, composed of limestones, dolomitic limestones, and some sandstones; (3) the Delaware Mountain sandstones; and (4) the Bone Spring limestone, which lies below the range of this temperature test.

THE TEMPERATURE CURVE

The temperature data are presented in graphic form in Figure 1 and produce a curve which is convex toward the depth axis. This form of curve indicates that the temperature gradient increases with depth. The rate of change, however, is not constant, and the curve may be regarded as composed of three components, each representing a more or less uniform gradient, and each represented in Figure 1 by a straight line (1, 2, 3). The computed reciprocal gradients based on the least-square adjustment of a straight line for different subdivisions of the curve are given in Table I.

[4] For a more complete stratigraphic description, see Walter B. Lang, "The Permian Formations of the Pecos Valley of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21 (1937), pp. 833–98.

[5] W. B. Lang, "Upper Permian Formations of Delaware Basin of Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), pp. 262–70.

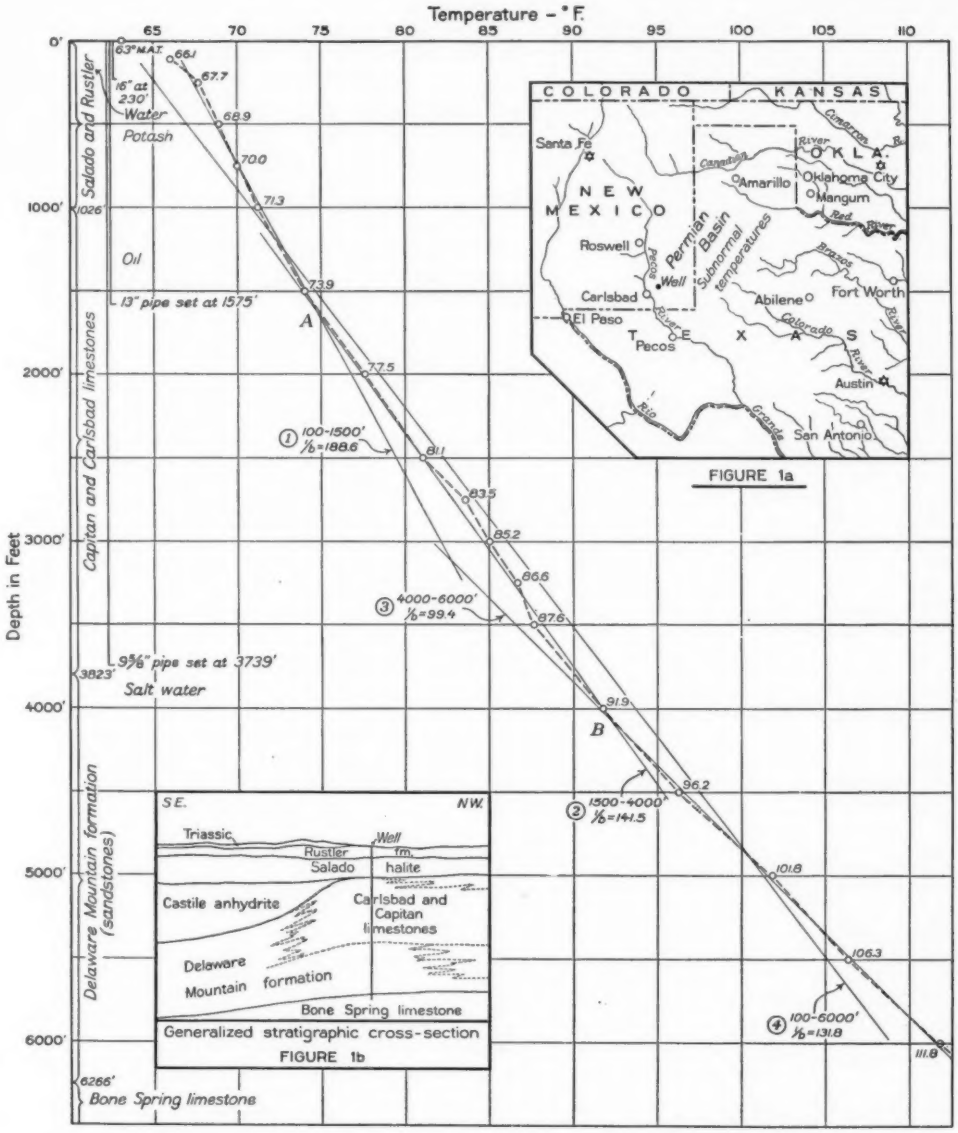

FIG. 1.—Depth-temperature curve of the Getty-Dooley well No. 7 near Carlsbad, Eddy County, New Mexico. Contrary to mathematical practice, the point of origin is put in the upper left-hand corner in order to place the depth axis in a more natural position for geological consideration.

TABLE I

Depth Range Feet	*Gradient °F/Foot*	*Reciprocal Gradient Feet/°F*	*Rock Type*	*Curve*
250–1,000	0.00476	210.1	Saline section	
250–1,500	0.00496	201.7	Salines and limestone	
100–1,500	0.00530	188.6	Salines and limestone	(1)
1,500–4,000	0.00707	141.5	Limestone	(2)
4,000–6,000	0.01006	99.4	Sandstone	(3)
100–6,000	0.00759	131.8	All	(4)

TABLE II

TABLE OF OBSERVED AND CALCULATED TEMPERATURES, GETTY-DOOLEY WELL NO. 7

Depth Feet	*Observed Temperature °F*	*Calculated Temperatures—°F with Deviation from Observed Value*							
		100–1,500 Feet (1)		*1,500–4,000 Feet (2)*		*4,000–6,000 Feet (3)*		*100–6,000 Feet (4)*	
100	66.1	66.6	−0.5					64.1	+2.0
250	67.7	67.4	+0.3					65.3	+2.4
500	68.9	68.7	+0.2					67.2	+1.7
750	70.0	70.0	0.0					69.1	+0.9
1,000	71.3	71.3	0.0					71.0	+0.3
1,500	73.9	74.0	−0.1	74.1	−0.2			74.8	−0.9
2,000	77.5			77.6	−0.1			78.6	−1.1
2,500	81.1			81.2	−0.1			82.3	−1.2
2,750	83.5			82.9	+0.6			84.2	−0.7
3,000	85.2			84.7	+0.5			86.1	−0.9
3,250	86.6			86.5	+0.1			88.0	−1.4
3,500	87.6			88.2	−0.6			89.9	−2.3
4,000	91.7			91.8	−0.1	91.5	+0.2	93.7	−2.0
4,500	96.2					96.5	−0.3	97.5	−1.3
5,000	101.8					101.6	+0.2	101.3	+0.5
5,500	106.3					106.6	−0.3	105.1	+1.2
6,000	111.8					111.6	+0.2	108.9	+2.9

RELATION OF TEMPERATURE CURVE TO STRATIGRAPHIC SECTION

Figure 1 shows that the points of intersection of the adjusted gradients (1, 2, 3), *A* and *B*, are at positions which are in remarkable agreement with the contacts of the major lithologic units previously mentioned despite the fact that most of the temperature measurements were made at widely spaced intervals of 500 feet (Table II). Closer spacing of the well-temperature measurements would have served better to fix the position of the curve and might have developed an even more intimate relationship than the curve now bears to the stratigraphic section.

This obvious relationship suggests a very definite correlation between kind of rock and rate of heat conduction, especially in view of the fact that the lowest geothermal gradient of the well (0.00476 or

210.1 ft. per °F., from 250 to 1,000 feet of depth) lies in that unit possessing rocks of the highest thermal conductivity, namely, halite and anhydrite. By including 500 feet of the limestone section below, the gradient is increased only to 0.00496 or 201.7 feet per degree. The presence of the Castile anhydrite on the southeast side of the reef crest and of the lateral gradation of the limestone into anhydritic members on the northwest accounts for this moderate increase. However, the limestone section from 1,500 to 4,000 feet shows a much higher gradient and likewise the sandstone section from 4,000 to 6,000 feet a still higher gradient of 0.01006 or 99.4 feet per degree. Thus it is evident that the rate of heat conduction or gradient may be correlated with the kind of rock present.

This relationship therefore suggests a direct method for determining in place the thermal conductivity coefficients of the different types of rocks as they exist under natural conditions. The meager data that are now available are the product of laboratory experiment and in most cases represent the results of tests on unusual specimens or specimens in a state abnormal to their natural environment. For purposes of extrapolation beyond the reach of well measurement the coefficients of conductivity used must be representative of the rocks as they occur in the earth. The results of many geothermal measurements are now available, but a systematic and precise correlation of the different kinds of rocks under different modifying conditions and their rates of heat conduction have never been attempted. Such a method may prove more fruitful than the direct laboratory procedure.

EFFECT OF WATER

Water increases the conductivity of any rock in which it may be present. The water may completely fill the pore space, or it may be present only as a film on the surface of the constituent rock particles. Under the second condition rocks would be reported "dry" when drilled, yet an imperceptible amount of moisture may produce almost as great an effect on the thermal conductivity of the rock as that produced by saturation. No appropriate data are available to show the effect on the thermal conductivity of rocks of different amounts of water, of water with different salts in solution, or of oils[6] and gases.

The rocks of the Permian Basin would be considered dry. Such ground water as is present occurs in aquifers or in perched water tables usually separated by widely spaced intervals of "dry" rock.

[6] The oil production zone of the Getty pool lies here at a depth of 1,325–1,385 feet. In 10 years (to January, 1937) less than 135,000 bbls. of oil have been withdrawn. The oil is of 20° A.P.I. gravity with very little associated gas. This small withdrawal of oil has not disturbed the temperature gradient.

The variations in the curve for the well in the lower part of the limestone section are believed to be caused by the presence of moisture. Also the sharp deviation in the curve above 250 feet is considered to be a direct result of a change in the moisture content of the rocks above the perched water table at 180 feet. Salt water was reported to be present in the 3,800 to 4,000-foot zone. It shows no measurable effect on the trend of the curve and no active circulation of this water is believed to exist.

HEAT OF SOLUTION

Richardson and Wells[7] have shown that most of the minerals which occur in the Salado when dissolved in water absorb heat. The low gradient in the Permian Basin is a regional effect. If solution of parts of the Salado is the cause of this effect it must also be regional in extent. But no general regional solution of this formation is evident. In Permian time the Salado was eroded away west of the Pecos River. As this was a surface process and occurred over 200,000,000 years ago, no present temperature variations can be assigned to it. In late geologic time the salt has been dissolved locally, especially in the Pecos Valley. However, the volume of chlorides and sulphates annually removed by the Pecos River[8] can not account even for a barely appreciable local heat effect and no such effect is evident. Also the sodium-potassium ratio of the Pecos water is normal for surface drainage of a semi-arid country and does not suggest that the potash-bearing salts are being dissolved.

One general and extensive chemical reaction in the basin is the alteration of anhydrite to gypsum, which has taken place whenever anhydrite has been exposed at the surface. Available evidence shows that in places this alteration process has extended as much as 1,000 feet below the surface, though in general it extends only a few hundred feet. This change is an exothermic reaction which evolves 4.61 kilogram calories.[9] The direct solution of anhydrite develops 3.92 kilogram calories, a process that in nature occurs in few places, as the alteration of anhydrite to gypsum generally precedes the solution of calcium sulphate. The solution of gypsum absorbs only 0.69 kilogram calories. Thus chemical heat effects involving anhydrite are either too small or in the wrong direction to explain the subnormal temperatures of the Permian Basin.

[7] L. J. Richardson and R. C. Wells, "The Heat of Solution of Some Potash Minerals," *Jour. Wash. Acad. Sci.*, Vol. 21, No. 11 (1931), pp. 243–48.

[8] *Op. cit.*, p. 248.

[9] Landolt-Börnstein, *Physikalisch-Chemische Tabellen*. Berlin, (1931).

IGNEOUS INTRUSIONS

The area of the Permian Basin is one of sedimentary deposition where igneous rocks are seldom encountered. The pre-Cambrian rocks probably lie at a depth of 12,000 feet or more. In the area of southeastern New Mexico, a few small lamprophyre dikes and sills are exposed and others have been encountered in subsurface by the drill. They appear to have been injected into the sediments at low temperatures, for they have caused but little if any alteration of the contact surfaces. These dikes are probably of the same age as the post-Cretaceous igneous intrusives of the White, Carrizo, and Capitan Mountains of New Mexico. A determination of the helium-uranium ratio in drill cuttings from an igneous intrusion in the Salado gave an age of 30 million years.[10] This is a minimum value; the true age of the intrusion may exceed this value by 10 or 20 million years.

These small scattered igneous intrusions affected the geothermal gradient only locally. In the span of 30 million years practically all vestige of this heat must now have been dissipated. These dikes might be considered apophyses from a large deep-seated intrusion. Even so, the net result of such an intrusion would be to raise the regional temperature and steepen the gradients but not materially to alter the relationship which the gradients in the different rocks now bear to one another.

EFFECT OF RADIOACTIVITY

In view of the importance of potassium as a constituent part of the earth's crust[11] and the high radiothermal value accordingly attributed to it, consideration of its effect on geothermal gradients in an area where it is abundant should not be neglected. Radioactivity has been suggested as one of the sources of the heat of the earth. J. J. Thomson[12] in 1905 demonstrated that rubidium and an alloy of sodium and potassium emitted negative corpuscles. Campbell and Wood,[13] in 1906, announced that potassium possessed radioactive properties. Smythe and Hemmindinger[14] have recently demonstrated that this radioactive property is due only to the potassium isotope 40. In 1926

[10] W. D. Urry, Committee on geologic time, Nat. Research Council (1936), p. 40.

[11] F. W. Clarke, "Data of Geochemistry," *Bull. U. S. Geol. Survey* 770 (1924), p. 22. W. D. Urry, "Radioactive Measurements," *Proc. Amer. Acad. Art. and Sci.*, Vol. 68 (1933), pp. 137–44.

[12] J. J. Thomson, *Phil. Mag.*, (6), Vol. 10 (1905), pp. 584–90.

[13] N. R. Campbell and A. Wood, *Proc. Cambridge Phil. Soc.*, Vol. 14 (1906), p. 15.

[14] W. R. Smythe and A. Hemmindinger, "The Radioactive Isotope of Potassium," *Physical Review* (2) Vol. 51 (1937), No. 3, pp. 178–82.

Holmes and Lawson[15] presented evidence to show that the radiothermal energy of potassium in the earth is of the same order of importance as that of uranium or thorium. Joly[16] gives the heat value of one gram of potassium as probably 3.56×10^{-12} calories per second.

The average value for the evolution of radioactive heat based on the uranium and thorium series for sedimentary rocks is 16.6×10^{-14} calories per gram per sec. This is less than half the amount considered to be an average for the granites, including the syenites and monzonites (42.1×10^{-14}), which are the most radioactive of the igneous rocks. This factor of 42.1×10^{-14} cal. gram/sec. is the sum of the energies of uranium (16.8×10^{-14}), thorium (13.2×10^{-14}), and potassium (12.1×10^{-14}). The radioactive elements are sparsely disseminated throughout most rocks and constitute an exceedingly small percentage of the whole. Goranson[17] gives a world average of 24×10^{-14}. In the granites the amount of potassium present seldom exceeds 7 per cent; is generally less than 5 per cent. What per cent of this potassium is K^{40} is not known. There is, however, an interesting relationship between the normal percentage of potassium present in an igneous rock of any type and the radioactive value. This radioactive value is rudely proportional to the percentage of potash present and is inversely proportional to the density of igneous rocks in the classification series; the granites of lowest density (d—2.7) possess the greatest radioactive value, whereas the ultra basic rocks, peridotites, *et cetera* (d—3.3) are the least radioactive. These relationships of mineral and chemical composition to density and radioactivity, also hold true for the meteorites.

The literature of radioactivity is without record of the measurement of any heat produced in the earth that is definitely known to be of radioactive origin. This status may be due to one or more of the following causes: (1) all the radioactive energy released within the rocks of the earth may not be converted into heat despite the fact that laboratory experiments show that the measured and computed values of this energy are the same,[18] (2) if the released energy is converted into heat the amount of heat so produced is too small to be recorded by geothermal instruments now in use, or, (3) other factors controlling heat conduction obscure the feeble effect of radioactivity.

[15] A. Holmes and R. W. Lawson, "Potassium and the Heat of the Earth," *Nature*, Vol. 117 (1926), No. 2948, pp. 620–21.

[16] J. Joly, *The Surface History of the Earth* (Oxford, 1930), p. 60.

[17] R. W. Goranson, "The Density of the Island of Hawaii and the Density Distribution in the Earth's Crust," *Amer. Jour. Sci.*, Vol. 16 (1928), pp. 89–120.

[18] A. Holmes, "Radioactivity and Earth Movements," *Trans. Geol. Soc. of Glasgow*, Vol. 18 (1931), p. 572.

An opportunity to test for evidence of radioactive heat in the earth is afforded by the uraninite veins on the east side of Great Bear Lake, North West Territory, Canada. Two parallel 4-inch veins of uraninite[19] 300 feet apart and with vertical dips are traceable for many hundreds of feet upon the surface. The veins occur near the contact of granite intruded into lava flows and are thought to have a genetic relation to the granite. A thermal gradient in the enclosing rock normal to the face of the veins should be detectable at depth if the heat of radioactivity is of any consequence.

THE GRANITIC ROCKS OF THE SIERRA NEVADA

The Sierra Nevada of California is an extensive and relatively uniform granitic mass. The composition varies slightly from a granodiorite to a quartz-monzonite with an outer gabbroic shell appearing on the western flank of the mountains. This batholith was intruded in Jurassic or early Cretaceous time. The potassium content of this mass ranges from 2.5 to 5.5 per cent.[20] There is only one record of a uranium determination of this rock but there is no reason to doubt that the radioactive value for this massif will deviate much from the normal for a rock of this type. Yet such temperature data as are available for the Sierras[21] suggest that the area is subnormal and demonstrate that cooling of the intruded mass has proceeded to a lower temperature level (190 ft./°F.) than that of contiguous areas (Cenozoic deposits of the Great Valley of California (60 ft./°F.)) in spite of any support that the heat of radioactivity may have been able to contribute. Here neither potassium nor the other radioactive elements are capable of maintaining a normal temperature gradient.

It is of further interest to note that these younger and less radioactive Cenozoic sedimentary deposits of the valley, which acquired the temperature of the basin waters[22] at the time of their deposition, are now far warmer for equivalent depths below sea level than the more radioactive granitic rocks of the Sierras that were intruded at a high temperature. The sedimentary deposits of the valley, therefore,

[19] Hugh S. Spence, "The Pitchblende and Silver Discoveries at Great Bear Lake, Northwest Territories," *Pub. No. 727, Canada Department of Mines, Mines Branch, Mineral Resources* (1932), pp. 55–92.

[20] *U. S. Geol. Survey Prof. Paper 99* (1917).

[21] W. D. Johnston, Jr., "Geothermal Gradient of the Mother Lode Belt, California: A Reply," *Jour. Wash. Acad. Sci.*, Vol. 22, No. 14 (1932), pp. 390–93.

[22] The mean annual temperature of the surface water in Golden Gate, San Francisco Bay, is 55.5°F. Neither the water at depth nor that farther within the bay has a mean annual temperature that differs by much more than a degree from the surface temperature at the entrance. The temperature of the Tertiary waters that occupied the region of the Great Valley were undoubtedly of the same order of value.

have become heated since their deposition, while the granitic mass has lost heat even to a lower degree than that which is considered a normal gradient (Fig. 2).

The tilting of the Sierra Nevada monocline should raise with it the isogeotherms and cause a flow of heat from there to the assembled valley deposits. However, the temperature gradient in the valley deposits could not be made to exceed that in the mountain mass, as has been noted, for any equivalent datum plane, by this process. This condition, therefore, must be caused by other agencies, the more important of which may be (1) the greater thermal conductivity of

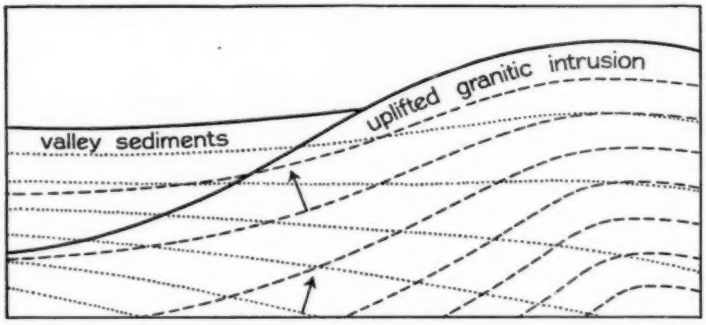

FIG. 2.—A diagram showing the effect upon the isogeotherms of an exchange of gradients between two areas, one an uplifted granitic area, originally warm; the other a synclinal basin filled with onlapping sediments. The dashed lines represent an initially high gradient in the uplifted granitic area and a low gradient in the syncline. The dotted lines show the result of the exchange of gradients between the two areas. The arrows indicate the direction of heat flow.

the granitic rocks, and (2) the greater surface area here exposed to cooling in lower mean annual air temperatures, or (3) exothermic reactions within or beneath the younger valley sediments. This anomalous condition, which is suggested by meager data, affords an interesting field for further investigation and study.

THE POTASH BEDS OF THE PERMIAN BASIN

The geothermal gradient in the Dooley well between 250 and 1,000 feet is 0.00476°F. per foot or 210 feet per degree, which is very low and the unadjusted gradient curve is here almost a straight line. Between 360 and 1,026 feet is the Salado halite, which contains with the halite and anhydrite many beds of potash in the form of polyhalite, sylvite, langbeinite, etc. The sylvite showings in this and adjacent wells represent the thin edges of beds which at distances of

4 and 7 miles are of such thickness and richness as to support two profitable potash mines. Here the average potash content for a 500-foot section is 2.7 per cent. If the potassium content of the 10-foot productive bed in either mine were concentrated it would form a solid bed more than 2 feet thick. However, temperature tests made in these beds by the writer indicate that gradients for these mine areas rich in potassium are not different from those found in wells in the immediate vicinity. The temperature gradient of the Dooley well where it passes through the potash zone does not indicate any local generation of heat[23] (Fig. 3).

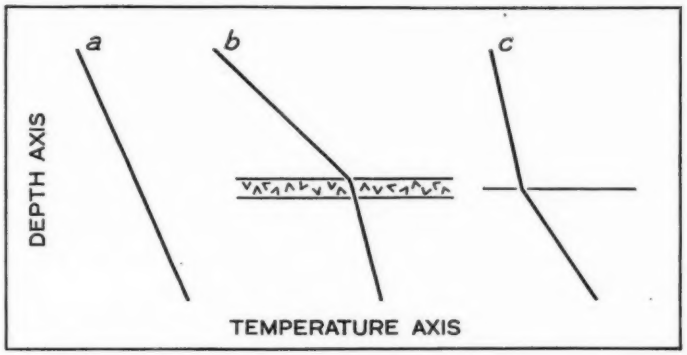

FIG. 3.—Types of geothermal curves: (a) a geothermal-gradient curve through a formation of uniform conductivity; (b) effect produced by the introduction of a local heat source; (c) type of curve produced where beds of higher conductivity overlie beds of lower conductivity.

Let a section of the Salado halite in the potash-rich area that lies at depth of 500 to 1,000 feet be selected and an estimate of the total amount of potassium contained within this 500 feet of section be made: calculating the total amount of potash in the more concentrated potash beds whose values have been determined by analysis, and adding to this a factor (500×1.5 per cent) to represent the disseminated potash in the intervening beds, it is found that there are 160 inches of potash in this section. This amount of potash is equivalent to 133 inches of potassium.

Now by employing Joly's estimate of 3.56×10^{-12} gram calories /sec.[24] and taking the density as unity (density of potassium = 0.87)

[23] M. C. Dauzère, "Conductibilité électrique de l'air dans une mine de potasse de Catalogne," *Comptes Rendus*, Vol. 204 (1937), No. 1, pp. 38–39.

[24] *Op. cit.*, p. 60.

then 133 inches of potassium (=337.8 cm.) is equivalent to $1{,}202.5\times10^{-12}$ gram calories per sec. Referring this value to the formula of Van Orstrand[25] for computing the rise in temperature due to a heat source:

$$Vq=q/pc$$

where the rise in temperature of 1 cc. of rock at the source of density p, and specific heat c is due to the development of q calories of heat per sq. cm. per sec. on the plane $x=x'$.

$$Vq=\frac{1{,}202.5\times10^{-12}}{2.8\times0.25}=172\times10^{-11}$$

$$V=\frac{Vqx'}{\kappa}=\frac{172\times10^{-11}(x')}{0.0064}=2.7\times10^{-7}\times30.48\times x''$$

where κ is the constant 0.0064; 30.48 the conversion factor, and x'' the depth to the bed producing heat.

$$V=82\times10^{-7}\times x''$$

Now if all of the radioactive energy in 133 inches of potassium be considered as concentrated at a point 1,000 feet below the surface, then substituting 1,000 for x'',

$$V=82\times10^{-7}\times10^{3}=0.0082°\text{C. or } 0.015°\text{F.}$$

Therefore the maximum increase in temperature attainable by the concentration of 11 feet of potassium at 1,000 feet below the surface, all of which is assumed to be radioactive, is only 0.015°F. Obviously the scattering of this amount of potassium through a 500-foot section would reduce the value, and the radioactivity of potassium can not be considered as having material influence on the geothermal gradients of the Permian Basin.

The potash mines in northern Germany are reported to have a normal temperature gradient, but in the south many mines show high temperatures. Koenigsberger[26] has calculated that the radioactive heat of a bed of pure sylvite 100 meters thick could only account for an increase gradient of 1.2 per cent of the normal 3×10^{-4} whereas some German potash mines have a temperature gradient of 20 to 50 per cent higher than normal. This obviously can not be due to the radioactive heat of potassium. Therefore in Germany the radioactive

[25] C. E. Van Orstrand, "On the Flow of Heat from a Rock Stratum in which Heat is Being Generated," *Jour. Wash. Acad. Sci.*, Vol. 22 (1932), No. 20, 21 pp., 529–39.

[26] Joh. Koenigsberger, "Über die Wärmeentwicklung im Kalisalz durch das Radioacktive Kaliumisotop," *Kali und verwandte Salze*, Vol. 22 (1928), No. 17, pp. 266–67.

heat of potassium is found insufficient to account for certain high-temperature gradients, and this condition is similar to that in the Permian Basin, where subnormal temperatures exist despite the presence of abundant potassium.

SUMMARY

A subnormal gradient curve obtained in the Getty-Dooley well No. 7 in Eddy County, New Mexico, has been studied in relation to the nature of the rocks of the region. The stratigraphic section is divisible into three lithologic units: saline beds in the upper part, limestone in the middle part, and sandstone in the lower part. The gradient curve is also divisible into three subordinate trends or gradients, each distinct trend corresponding approximately with one of the lithologic units. There are apparently no other major factors in the area to control the form of the curve. Though there is an abundance of potassium present, the heat yielded by its radioactivity is of no consequence, theoretically or practically. This also raises the question whether or not the speculations concerning the heating effect of radioactivity at depth in the crust of the earth are valid. The character of this geothermal-gradient curve is therefore believed to change from point to point with the conductivity of the successive layers of rock.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 9 (SEPTEMBER, 1937), PP. 1206-1225

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

Introduction to Theoretical Seismology, Part I, Geodynamics. By J. B. MACELWANE. John Wiley and Sons, Inc. (1936). 366 pp., 67 figs., 15 pls., 40 tables, and many bibliographic references.

This long looked for volume comprises the following chapters: I. Stresses in an Elastic Solid; II. Elastic Strain; III. Relations between Stress and Strain; IV. Elastic Body Waves; V. Surface Waves on the Plane Boundary of an Isotropic Elastic Solid; VI. Vector Treatment of Elastic Waves; VII. Reflection and Refraction of Elastic Waves; VIII. Paths of Seismic Rays; IX. Interpretation of Seismograms; X. Determinations of Epicenters; XI. Depth of Focus. The book grew out of class-room lectures by Father Macelwane at the University of California and at Saint Louis University and is based on many sources, but particularly on B. Galitzin's *Vorlesungen über Seismometrie* and A. E. H. Love's *The Mathematical Theory of Elasticity.*

Part II, Seismometry, by F. W. Sohon, was published in 1932.

This important contribution to the literature of seismology should be in the reference library of all specialists in seismology and of students interested in the details of the classical theory of earthquake waves, a good cross section of the results of the study of seismographic records, and the basic theory of the propagation of seismic waves. Chapters I–VIII, inclusive, are deeply mathematical and will interest only the special student. The geologist who is interested in how the seismologist interprets seismograms and determines the position of the epicenter, the depth of focus, and the structure of the earth will find chapters IX–XI, and sections 100–110 in Chapter VIII, of interest and of value.

DONALD C. BARTON

HOUSTON, TEXAS
June 29, 1937

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*"Evolution of the Coahuila Peninsula, Mexico." I, "Relation of Structure, Stratigraphy, and Igneous Activity to an Early Continental Margin," by L. B. Kellum, R. W. Imlay, and W. G. Kane; II, "Geology of the Mountains Bordering the Valleys of Acatita and Las Delicias," by W. A. Kelly; III, "Geology of the Mountains West of the Laguna District," by L. B. Kellum; IV, "Igneous Phenomena and Geologic Structure near Mapimi," by Q. D. Singewald. *Bull. Geol. Soc. America,* Vol. 47 (July 31, 1936), pp. 969–1176.

Geologists have long noticed a peculiar structural zone in southern Coahuila and adjacent parts of northeastern Mexico. Here, through a distance of more than 200 miles, the dominant north-northwest Cordilleran trend is so deflected that the ranges strike east and west. Some idea of the origin of this feature was gained in 1923, when Emil Böse[1] described the "vestiges of an ancient continent" in the region. Within the east-west zone he

[1] Emil Böse, "Vestiges of an Ancient Continent in Northeast Mexico," *Amer. Jour. Sci.,* 5th ser., Vol. 6 (1923), pp. 127–38, 196–214.

showed that there exists a thick Mesozoic sedimentary sequence, including late Jurassic and early Cretaceous (Neocomian) deposits, but that farther north these deposits are wanting. In the northern area, as Böse observed near Las Delicias and elsewhere, the Mesozoic begins with the later Lower Cretaceous (Aptian), which transgresses an eroded floor of Paleozoic strata and granitic rocks. Evidently the existence of this early Mesozoic land area, bordered on the south by an area of geosynclinal deposition, had a strong influence on the structural features in southern Coahuila when the Mesozoic rocks were compressed later in the Tertiary.

"Böse's work was largely exploratory, and was considerably hampered by the turbulent conditions which existed in the country at the time. It was not until last year that geologists could learn the details of this geologically interesting area from the detailed descriptions, stratigraphic and structure sections, and areal maps contained in the group of papers under review. These papers are the product of a group of geologists from American universities who have been doing field work in the region since 1930, and are a truly fine example of the value of coöperative research focused on a single stratigraphic and tectonic problem. They are, besides, a monument to the leader and organizer of the investigation, Professor L. B. Kellum of the University of Michigan.

The first paper of the group, on the "Relation of Structure, Stratigraphy, and Igneous Activity to an Early Continental Margin," by Kellum, Imlay, and Kane, summarizes the broader results of the investigation, and brings in much additional information from adjacent areas. Speculations are offered on the origin of the regional structural features, and on their relations to problems of continental paleogeography and tectonics. Association members will recall a similar, shorter paper by the senior author which was published in the Mexican number of the *Bulletin*.[2]

The succeeding papers of the group under review describe the detailed geology of various parts of the region. That by Kelly on the mountains bordering the valleys of Acatita and Las Delicias describes a section of the old land area and the deposits which cover it. Those by Kellum and Imlay on the mountains west of the Laguna district, and the western part of the Sierra de Parras describe segments of the east-west structural zone. That by Singewald describes an area of Tertiary volcanic rocks. In addition to these papers, the same group of geologists has published two others on the region. Kellum[3] has described the geology of the Sierra de Jimulco, and Imlay[4] the middle part of the Sierra de Parras. Several papers on other areas are not yet published, although their general results are summarized in the first paper of the group. To complete the geological story, reference should also be made to a study done independently by R. E. King[5] on the stratigraphy and structure of the Permian rocks northwest of Las Delicias, within the old land area.

[2] L. B. Kellum, "Paleogeography of Parts of Border Province of Mexico Adjacent to West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 417–32.

[3] L. B. Kellum, "Reconnaissance Studies in the Sierra de Jimulco, Mexico," *Bull. Geol. Soc. Amer.*, Vol. 43 (1932), pp. 541–564.

[4] R. W. Imlay, "Geology of the Middle Part of the Sierra de Paras, Coahuila, Mexico," *Bull. Geol. Soc. Amer.*, Vol. 48 (1937), pp. 587–630.

[5] R. E. King, "The Permian of Southwestern Coahuila, Mexico," *Amer. Jour. Sci.*, 5th ser., Vol. 27 (1934), pp. 98–112.

Taken together, the group of reports makes clear the geological features of an area in southwestern Coahuila, which is 150 miles long east and west, by 100 miles wide north and south.

In their stratigraphic studies the authors follow the American, rather than the prevailing Mexican custom, of mapping by lithologic units, and reserve the use of European stage names for regional discussions in which it is necessary to consider the time equivalents of the different facies. This seems to be a happy solution to the perennial question of whether to use time or lithologic units in field work. Many of the proposed formation names are new, but some are borrowed from the earlier paper by Burrows[6] on the Rio Conchos area, Chihuahua, and one is taken from trans-Pecos Texas. The use of the latter, the Torcer formation, which Adkins[7] applied to the Neocomian rocks of the Malone Mountain section, seems unfortunate at this time, since the Neocomian of that area is as yet poorly defined. It should be noted also that the Rio Conchos area, in which the type localities of Burrow's names are located, has not yet received the detailed study which the authors have given to their own districts, so that the exact correlation of the typical formations is not possible at this time. The authors do not attempt, however, to use the Rio Conchos names for time equivalents, but apply them to equivalent facies of about the same age. Thus the name Aurora is used for massive, mountain-forming, rudistid limestones of Aptian and Albian age.

As shown by the study, the ancient continent described by Böse is really a southward-projecting promontory of the main North American land mass of Mesozoic time, which they aptly call the "Coahuila peninsula." During Jurassic and early Cretaceous (Neocomian) time, deposits were laid down east, south, and west of it, as shown by scattered exposures that are found in a semicircle that extends southeast from Cuatro Cienegas to Monterrey and Saltillo, thence westward to Torreon, and thence north-northwestward to Malone Mountain in trans-Pecos Texas. Sediments of this age become more clastic toward the edge of the peninsula. South of Cuatro Cienegas they are a mass of sandstone, arkose, and conglomerate, which was presumably laid down as a delta in an arm of the sea on the east side of the peninsula.

During Aptian and Albian time, when the peninsula was covered by sediments, its area was for a long period more or less sheltered from the sea, so that fossiliferous limestones are interbedded with numerous thin to thick layers of gypsum (Cuchillo formation). Eastward, southward, and westward from the peninsula, these are replaced by open-sea deposits. The borders of the lagoonal area can be mapped with some precision, and resemble strikingly the outline of the peninsula as it existed in earlier Mesozoic time, a fact that is made clear for the first time in this study.

As a result of Tertiary movements, the peninsula and its cover of Cretaceous sedimentary rocks has been folded into a series of broad upwarps and downwarps, with only occasional narrow zones of sharp folding. Some normal faults have been observed by King and Kelly near Las Delicias.

[6] R. H. Burrows, "Geology of Northern Mexico," *Bol. Soc. Geol. Mexicana*, Vol. 7 (1910), pp. 1–15.

[7] W. S. Adkins, in "The Geology of Texas," Vol. 1, "Stratigraphy," *University of Texas Bull. 3232* (1933), pp. 286–91.

King also explained some of the present topographic features of the Las Delicias valley by moderately recent normal faulting of Basin and Range type, but the present authors minimize this feature, stating that most of the present topography of broad-backed mountains, steep escarpments, and broad intermontane basins is to be explained by differential erosion, which has been particularly effective in the alternating limestones and gypsums of the Cuchillo formation. Granitic rocks and Permian volcanic rocks are found in the pre-Aptian basement of the peninsula, but there was no further igneous activity in Mesozoic or Cenozoic time in its southern part.

South and west of the peninsula, the authors' detailed studies show a great change in the stratigraphy and structure. This is the region of east-west folding, and a part of the area of Jurassic and Neocomian deposition. Flanking the old peninsular area on the south is an east-west topographic depression, the Parras Basin, beyond which rise the limestone ranges of the Sierra de Parras, the Sierra de Jimulco, and some lesser ridges. The limestone ranges form an anticlinorium and are composed of Jurassic and Lower Cretaceous rocks of which about 8,000 feet are exposed. The basin on the north is a synclinorium of Upper Cretaceous rocks. Its highest beds (Difunta formation) are a mass of shales and sandstones more than 12,000 feet thick containing igneous rock detritals, and with interbedded conglomerates composed of Lower Cretaceous limestone fragments. The authors believe that the basin began to take form at the time of deposition of these beds, and that they were not deposited very far north or south of it. To the reviewer, the Difunta formation strongly resembles the deposits known as the Flysch in Europe, which were laid down in great masses in the mobile belts, in basins that began to be differentiated in the early part of the orogenic episode.

The limestone ranges on the south are intensely folded, but to continue the comparison with Europe, their structure resembles more that of the Jura Mountains than that of the Alps. The nature of the folding is beautifully shown in the structure sections that accompany Imlay's papers. The folds consist of long, parallel, closely spaced anticlines and synclines, in part symmetrical, but in many places overturned toward the north, and in a few places toward the south. Local variations in pitch bring in older or younger formations along their crests, and now and then an anticline dies out along the strike, or new anticlines are implanted between the old. A few tear faults cross the folds transversely, but despite the intensity of the deformation, overthrusts are generally absent. They are found only near Torreon at the west end of the zone, where the west-trending folds bend southwest through the Sierra de Jimulco and then northwest through the Sierra Hispaña. Here the rocks at the western end of the Sierra de Parras have ridden some distance over those on the north, and those of the Sierra Hispaña over those on the northeast.

The authors point out that these overthrusts form the western part of a zone of overturning, which seems to extend along the flanks of the old peninsula. Farther east in the Sierra de Parras it is represented by a strong overturn, without faulting, of the Lower Cretaceous beds over the Upper Cretaceous beds of the Parras Basin. Beyond, east and northeast of Saltillo, where the strike remains east-west, the zone of overturning bends toward the north across the strike of the beds, and brings about a remarkable set

of structural features first described by Böse. Here, the east-west striking folds pitch to the west, so that east of Saltillo they are composed of Jurassic and Lower Cretaceous rocks, and west of Saltillo of Upper Cretaceous rocks. Most of the westward pitch takes place at the zone of overturning, and is so abrupt that the rocks on the crest of each east-west striking anticline are overturned westward.

In contrast to the old peninsular area on the north, there has been some igneous activity in the east-west structural zone. The authors point out that four districts in which intrusive rocks are prominent occur south of the old peninsula and tend to be arranged in an east-west direction. They also note areas of volcanic rocks in this region, and one of these is described in some detail by Singewald. In this connection, Kellum[8] effectively disposes of an interpretation which seems to have been widely held by mining geologists working in Mexico, that the folding has been caused by the intrusion of igneous rocks. This inference is perhaps pardonable, since mining camps are likely to lie near the centers of igneous activity, but regional investigations such as that under review show that the folding extends over a vast area, and that the intrusions are local. It is probable that both folding and intrusion are manifestations of the same forces, and that both have come about from the great compression that has taken place in the Mexican region.

The region east and northeast of the old peninsula is not described in any detailed reports, but its general features are discussed in the opening paper. Here a bundle of ranges extends north-northwest as a prong of the Sierra Madre, and one of them, the Sierra del Carmen, crosses the Rio Grande into the Big Bend region of Texas. Like the other mountains of the region, they are composed of Lower Cretaceous limestones, and in their southern part, near Cuatro Cienegas, these are underlain by Jurassic and Neocomian rocks. Farther north, however, near Boquillas on the Rio Grande, the Albian lies on pre-Mesozoic schists, so that this section lies within the continental area.

The ranges northeast of the peninsula are composed of rocks that are more strongly folded than the peninsular area, but which are somewhat more openly folded than those in the east-west zone south of it. Along the edge of the peninsular area they are overturned westward toward it. The reviewer has gained the impression from conversation with C. L. Baker, who has seen much of this section, that farther east the overturning reverses to an eastward direction, so that this prong of the Sierra Madre is a two-sided orogenic zone overturned toward the pre-Aptian peninsula on the west, and toward the Coastal Plain on the east. It would seem to present a fruitful field for later tectonic studies similar to that under review.

The authors do not discuss at much length the time relations of the structural features, which is to be regretted. As illustrated by Reed's[9] recent studies in California the relation of the various structural features to time is quite as important and interesting as their geometric relations. It is true, however, that in the region studied most of the structural features are not easy to date. In greater part they are younger than the Difunta formation

[8] L. B. Kellum, "Geology of the Mountains West of the Laguna District," *Bull. Geol. Soc. Amer.*, Vol. 47 (1936), p. 1045.

[9] R. D. Reed and J. S. Hollister, "Structural Evolution of Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 1682–90.
R. D. Reed, "Southern California as a Structural Type," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21 (1937), pp. 549–59.

of the Upper Cretaceous, which in many places is the last formation deposited. Some younger gravels and conglomerates, in greater part Tertiary, but perhaps partly Cretaceous, are recorded in a few places, and may be more closely related to the orogeny. One such area of gravels has been overriden by the overthrust of the Sierra Hispaña. The reviewer gains the impression from the various papers that the greater part of the folding was completed in the early Tertiary, and is older than the volcanic rocks. In later Tertiary and Quaternary time, the history of the region has apparently been one of regional uplift and profound erosion, by which the landscape was carved into its present form. In places, however, there has been a certain amount of normal faulting, as is recognized in the area of volcanic rocks near Mapimi by Singewald, and along the west side of the valley of Las Delicias by King and Kelly.

The region studied by the authors probably lies west of any possible oil producing territory in Mexico but the investigation, competently carried out, and yielding such a wealth of conclusions in the field of tectonics and paleogeography, should be of interest to all petroleum geologists.

WASHINGTON, D. C.
July, 1937

PHILIP B. KING[10]

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*"O Cretaceo de Sergipe" (Cretaceous of the State of Sergipe). By CARLOTTA JOAQUINA MAURY. *Monographias do Serviço Geologico e Mineralogico do Brasil, Monographia XI* (1936). Quarto, text 283 pp., and 28 plates with explanations bound separately. Publication in Portuguese and English.

This publication describes Cretaceous formations and fossils of the state of Sergipe, Brazil, and devotes short chapters to the study of oölites, particularly those of Sergipe, and to two Tertiary drill cores from shallow wells at the seaport of Aracaju.

The first 47 pages are concerned with historical summary, descriptions of stratigraphic units, oölites, the Tertiary drill cores, and the general correlation of the Brazilian Cretaceous formations with other areas. Data used in the discussions are from various sources. Fossils on which the systematic part of the paper is based are from old collections and from recent collections made by Moraes Rego. Most of the field work done up to the present time is of a reconnaissance nature.

The Cretaceous in Sergipe is believed to consist of the Estancia, Baixo São Francisco, and Sergipe series. No thickness measurements are available. The Estancia shales and sandstones are thought to be the correlative of the Jatoba-Buique series of Pernambuco and Bahia which contains *Lepidotus* scales suggestive of a Cretaceous age. Underlying stratigraphic relationships are still poorly understood. The limestones and sandstones of the Baixo São Francisco have not yielded organic remains, but field evidences indicate that the series lies under Middle Albian and above Neocomian.

The Sergipe series has a varied lithologic character, is richly fossiliferous, and is divided into three stages: Middle Albian (extending into Upper Albian), Lower Turonian, and Maestrichtian. The first stage is composed, from below upward, of the Lastro oölitic limestone, the Aroeira brown sandstone and the Garajau beds. Ammonites such as *Puzosia* and *Oxytropidoceras*, and other fossils, point to a Middle Albian age, but the presence of the ammonite genus *Pervinquieria* indicates that deposition continued into early Upper Albian. A zone of *Exogyra* is likewise present in these strata.

[10] Published by permission of the director, United States Geological Survey.

The Bom Jesus limestone, near Laranjeiras, contains *Vascoceras* and *Pseudaspidoceras* and is consequently Lower Turonian in age. These fossils have not been found elsewhere in Brazil. *Inoceramus labiatus* is reported from a limestone at Cedro on Rio Sergipe and the author considers these limestones Lower Turonian in age.

The youngest strata of the Sergipe are chalky limestone at Sapucary, and the presence in them of *Inoceramus posidonomyaformis* suggests a Maestrichtian (Fort Pierre) age.

These strata crop out inland forming bands approximately parallel with the shore, but separated from it by a Tertiary area. The author believes a definite Cretaceous-Tertiary contact will be traceable on further detailed field work, and the belief is substantiated by the meager Tertiary fauna recovered from the wells at Aracaju reaching depths of 79 and 96.5 meters.

The extensive correlation tables showing the approximate Cretaceous equivalents in Brazil, Venezuela, Colombia, Peru, Mexico, Texas, and other countries are well wrought out. The reviewer, however, finds no reason for the long out of date correlation which places all the Eagle Ford of Texas in Turonian, and the upper Georgetown beds and higher Washita in the Cenomanian. The Washita strata, except possibly the topmost Buda limestone have long been known to contain typical Upper Albian species of ammonites. The lower part of the Texas Eagle Ford is certainly Cenomanian.

The systematic part of the paper describes 3 species of marine flora, 2 species of fishes, 70 species of pelecypods, 33 species of gastropods, 24 species of ammonites, 19 species of echinoderms, and 1 species of foraminifera. Most of the species described are illustrated and many are new. The 28 full-tone plates are beautifully executed but appear to the reviewer to be unnecessarily wasteful of space. The ammonite descriptions follow the revisions of the author in a recent publication[1] on Brazil, but these fossils are in need of additional study and revision. The suture patterns are inadequately prepared and illustrated, and some of the generic assignments are out of date or open to question. For example, *Ammonites offarcinatus* White is referred to *Acanthoceras*. This genus, as now restricted, does not occur in the Middle Albian and the species, as pointed out by several authors, is probably *Douvilleiceras*. The description of *P. aroeira* does not conform to the figure (Pl. XXVI, Fig. 11). The figures of species referred to *Hemiaster* do not show the peripetalous fasciole characteristic of the genus. Descriptions of pelecypods and gastropods are well done and relationships of species are thoroughly discussed.

The paper as a whole is marred by numerous typographical errors, and it lacks a table of contents and systematic faunal tables which would have aided materially in clarifying the author's conception of the stratigraphy and fauna. This paper will be useful to those interested in the stratigraphy and fossil faunas of South America, and adds an important and comprehensive monograph to the long list of excellent papers on the geology and paleontology of South America published by the author.

GAYLE SCOTT

TEXAS CHRISTIAN UNIVERSITY
FORT WORTH, TEXAS
July 7, 1937

[1] Carlotta Joaquina Maury, "O Cretaceo da Parahyba do Norte," *Monographias do Serviço Geologico e Mineralogico do Brasil*, Vol. 8 (1930), pp. 272–99.

*"Lower Mississippi River Delta. Reports on the Geology of Plaquemines and St. Bernard Parishes." By R. J. RUSSELL, HENRY V. HOWE, JAMES H. MCGUIRT, C. F. DOHM, WADE HADLEY, JR., FRED B. KNIFFEN, and CLAIR A. BROWN. *Louisiana Geol. Survey Bull. 8* (1936). 454 pp., illus. 6×9 inches.

The report on the "Lower Mississippi River Delta" is a comprehensive work composed of several papers dealing with physiography, salt domes, petrography, mollusca, and Indian mounds. The part on physiography includes lengthy discussions of history, topography, natural levees, mudlumps, channels, lakes, sedimentation, subsidence, and quotations from Russell's excellent paper on physiography may serve to summarize a few of his most important observations. The Lower Delta is " . . . North America's most active geosyncline. This trough parallels the coast and has been filled to an extent of some 30,000 to 40,000 feet during Cenozoic time" (p. 154). "The deepest parts of the Mississippi channel are opposite New Orleans" (128 feet below sea-level), "Myrtle Grove, Point Michel, and Bolivar Point" (195 feet below sea-level) some distance from the Gulf of Mexico. "Passes not maintained have a tendency toward depths of less than 14 feet under best conditions and at times shoal to less than three." "Heavier salt water flows under fresh up the landward inclines of channels from the pass mouths"—at least as far as Baton Rouge where the channel is 60 feet below sea level (pp. 93–94). " . . . the Lower Delta has no great antiquity. The Forts subdelta appears to be the oldest land in the region, the St. Bernard-Bayou La Loutre subdelta of intermediate age, and the Balize subdelta youngest" (p. 158)—the last probably not over three or four centuries old. Russell believes " . . . the Mississippi River carries at least 2,000,000 tons of sediment to the Lower Delta each day, on the average" (p. 162).

" . . . if we were to follow and believe our leading students of shore lines we would come pretty well to the conclusion that most . . . flat coasts [are] rising, as evidenced by offshore bars, or barrier beaches" (pp. 49–50). The Mississippi Delta has been sinking. "The absurdity of the notion that obstructions initiate meanders should be clear in consideration of their development in homogeneous materials . . . " (p. 128). "The initiation of a bend, the start of meandering as the writer views the subject, under floodplain conditions is not so much related to deflections caused by obstructional irregularities along beds or banks as to presence of materials capable of easy removal at various points along the channel" (p. 132). This statement strikes the reviewer as very similar to the absurd notion, with the materials not entirely homogeneous. "The main Mississippi River channel and its more important distrubutary arms display little tendency toward meandering. These are streams of comparatively large volume and small effective stage differences. At the other extreme are small tidal channels with fully developed and intricate meander patterns" (p. 134). Russell believes, "Coarse layers . . . represent periods of low water, during which finer sediment has been winnowed effectively, leaving behind such grade sizes and shapes as turbulence has not been able to pump up. Fine layers . . . are more closely the undisturbed product of deposition during periods of subsiding flood stages" (p. 141). "Delta-flank depressions" are described on either side of the delta and on either side of each subdelta and are used as evidence of subsidence (pp. 163–64). " . . . drainage patterns determine future courses of mountains . . . " (p. 193).

The addition of a good map of the whole delta region would have added greatly to the report and the manner in which he criticises is tactless,—no doubt unintentionally. This report brings together a great amount of varied information, and reflects a wide familiarity with the history and problems of deltas and the Mississippi Delta in particular. Because it is the most recent and comprehensive paper on this subject it will be of value to students of isostasy, shore lines, sedimentation, and structure, as well as a guide book in exploring for petroleum on the delta country.

Howe and McGuirt give excellent descriptions of Lake Washington, Lake Hermitage, Garden Island Bay, and Venice salt domes. The first three produce oil, and Lake Washington contains an important sulphur deposit. They are piercement-type domes having cap rock within 900–2,200 feet of the surface. Useful paleontologic data are included and the authors suggest that Miocene formations are the lowest which, to date, have been reached by drilling.

The bibliography by Russell and Dohm appears to be unusually complete, the mechanical and petrographic analyses by Dohm aid in an understanding of the sediments, and the lists of recent mollusca by Hadley and the notes on Indian mounds by Kniffen and Brown round out the publication.

NORMAN THOMAS

FORT WORTH, TEXAS
July, 1937

Geologie von Asien. Erster Band, Erster Teil (1935). By KURT LEUCHS. 236 pp., 69 figs. Gebrüder Borntraeger, Berlin. Price (Erster Teil), RM 18.40.

During the last 12 years or more a group of distinguished geologists have been engaged in preparing and publishing a series of volumes on the geology of the earth (*Geologie der Erde*), under the editorship of Professor Erich Krenkel of the University of Leipzig. Aside from his editorial work, Professor Krenkel has published three volumes, or "Teile," on the Geology of Africa, including Arabia. Professor S. von Bubnoff has contributed some excellent volumes on the Geology of Europe, and Professor Gerth on the geology of South America. Dr. Kurt Leuchs has made himself responsible for the geology of Asia, and two of the four parts into which this work is divided have already appeared. The present review will deal with the first part, devoted to a brief general account of Asiatic geography and geology and to a more detailed discussion of the geology of Siberia or North Asia.

The general account of Asia contains 36 pages, 15 on the physiographic features and 21 on the structure and geologic history of Asia and on the basis for the classification of the continent into five major provinces: North Asia, Central Asia, East Asia, South Asia, and West Asia. Central Asia is defined as the area included within a line drawn as follows: from the point where the Amu Darya leaves the northwestern edge of the Turkestan Mountains to Tarbagatai and the Mongolian Altai, across the Tannu-ola and Khangai Mountains to the Yablonoi and Great Khingan ranges, then southward, east of the Ordos mass, to the Tsinling-shan, obliquely across the Tibetan chains where they bend southward toward Farther India, westward along the south edge of the Himalayas to their west end, and back to the Amu Darya.

The names of the other regions sufficiently define their boundaries, except for the fact that South Asia will apparently include only India. Arabia, as noted, has already been treated with Africa, and southeastern Asia is to be included with East Asia.

North Asia embraces 12½ million square kilometers of physiographically monotonous country, divisible into three parts: a featureless Western Siberia, a nearly featureless Middle Siberia, and a more diversified but poorly known Eastern Siberia. Middle Siberia is much like the Mid-Continent, with a thick section of flat-lying Cambro-Silurian marine strata and marginal marine and nonmarine Upper Paleozoic and nonmarine post-Paleozoic strata in the larger northern part. At the south margin lies the great mountainous Sayan-Baikal mass which Leuchs, following Obruchev, considers to be an ancient land mass, emergent during the entire Paleozoic and later, though somewhat modified in structure by post-Paleozoic folding movements.

Western Siberia had a history similar to that of northern Middle Siberia until about the end of the Paleozoic, when its western margin was strongly folded, the west edge of the folded area constituting the Ural Mountains. The eastern margin of the folded area and the presumably unfolded eastern part of Western Siberia subsided markedly during Mesozoic and Cenozoic time and is now covered with a great thickness of nearly flat-lying strata, both marine and nonmarine, dating from different parts of this long period. Western Siberia may thus be compared with such an area as the Mississippi Valley south of the Ohio River.

Eastern Siberia seems likewise to have developed much as did Central Siberia until the end of the Paleozoic and to have been folded during some of the Variscan (Appalachian) movements. During the Mesozoic it became separated from Central Siberia by a broad seaway stretching from the Arctic to the Pacific Ocean. The sediments deposited in this seaway were folded by the Cimmerian (Nevadian) movements. During the Tertiary, furthermore, the history of Eastern Siberia differed from that of the regions farther west and approximated that of other circum-Pacific regions. Thus Eastern Siberia seems to have had Mid-Continent tendencies until the end of the Paleozoic but to have developed Pacific tendencies since that time.

W. A. Obruchev's great volume on the geology of Siberia appeared in 1926, and summarized excellently the data available at that time. It is inevitable that Leuchs' volume, published only 9 years later, should lean heavily on the earlier volume, and should appear to be, to a considerable extent, a revision of that work. It is nevertheless an interesting and useful book, worth reading by any geologist whether or not he is familiar with the work of Obruchev. It includes an excellent summary of Siberian stratigraphy and structure, with many illuminating sketch maps and structure sections. The tectonic map is smaller in scale than Obruchev's and shows fewer data, but is more readily understood. In the absence of paleogeographic maps the present volume suffers in comparison with the earlier one.

A final short chapter gives an excellent summary of what is known about Siberian mineral deposits, and reproduces Obruchev's map. Most of the mineral deposits are found in the southerly, more mountainous part of Siberia. They include gold, copper, and other ore minerals, with enormous deposits of coal but practically no oil. In this respect the analogy with the Mid-Continent seems to break down.

Professor Leuchs' book, like the other volumes of the *Geologie der Erde*, is an impressive demonstration of the extent to which historical geology, European style, serves to characterize the regions of the earth and to permit them to be described briefly and intelligibly. Old consolidated areas grow outward by accretions of newly folded belts or locally become submerged and re-mobilized. Thus any continent or large part of a continent consists of a small number of types of province, each with a similar history, and each similar in history to the corresponding provinces in other continents. Each area is transgressed at certain periods—a few tens of periods altogether—and folded only at certain periods—30–40 altogether since the pre-Cambrian. Thus if we know the history of western Europe or of the United States, we have nothing new to learn in Northern Asia, except the distribution of provinces belonging to types already familiar. The events are the same and the results remarkably similar. Regional geology seems to be on the way to becoming a science: not so simple a science as Werner anticipated, perhaps, but simpler and more intelligible than many later geologists have thought possible. For this development we who are oil geologists have every right to be thankful; likewise, we have much reason to be grateful to the authors of the *Geologie der Erde* for bringing it so forcefully to our attention.

R. D. REED

LOS ANGELES, CALIFORNIA
July 12, 1937

RECENT PUBLICATIONS

AFRICA

"A Bibliography of South African Geology for the Years 1931 to 1935 Inclusive." *Mem. Geol. Survey Union South Africa*, No. 30 (Pretoria, 1937). 168 pp. (2,232 refs.).

ARGENTINA

*"Aguas, rocas y minerales del Campamento Tupungato" (Waters, Rocks, and Minerals of the Tupungato Field, Mendoza), by Maria Casanova de Chaudet. *Bol. Inform. Petrol.*, Vol. 14, No. 152 (Buenos Aires, April, 1937), pp. 21–38; 4 figs., 7 photomicrographs, 1 stratigraphic section.

*"División estratigráfica de los terrenos aflorantes en la región comprendida entre luján de Cuyo, Potrerillos y Tupungato" (Stratigraphy of the Region between Lujan de Cuyo, Potrerillos, and Tupungato), by Eduardo Truempy and Remigio Lhez. *Ibid.*, pp. 39–56; topographic map, stratigraphic column, and geologic sections.

ARIZONA

*"Geological Structures Mapped in Apache County, Arizona," by H. Roe. *Oil and Gas Jour.* (Tulsa, July 22, 1937), pp. 29–30; 1 map.

ARKANSAS

*"List of Arkansas Oil and Gas Wells," compiled under direction of George C. Branner by Mary L. Gibson. *Arkansas Geol. Survey Inform. Cir. 10* (Little Rock, 1937). 107 pp., 7 figs., 23 pls., 3 tables. 10.75×13.75 inches. Information on 2,109 wells drilled from 1887 to October 31, 1936, located

outside the intensively drilled areas in southern Arkansas. Maps of 70 counties, giving locations of wells, information on production, cost, history, possibilities. Price: in cardboard cover, $1.35; sales tax, $0.03; postage, $0.12; total, $1.50.

*"Geology and Mineral Resources of the Western Part of the Arkansas Coal Field," by T. A. Hendricks and Bryan Parks. *U. S. Geol. Survey Bull. 847–E* (1937), pp. 189–224, Pl. 35 (map of geologic structure and resources). Supt. Documents, Washington, D. C. Price, $0.25.

AUSTRIA

*"Das Ölfeld von Zistersdorf in Niederösterreich" (The Zisterdorf Oil Field in Lower Austria), by Karl Friedl. *Petrol. Zeit.* (Berlin), Vol. 33, No. 22 (June 2, 1937), pp. 13–24; 2 figs.

*"Die Oelaussichten am Ostrande der Alpen" (Oil Prospects on the Eastern Border of the Alps), by Lukas Waagen. *Bohrtechniker-Zeitung*, No. 7 (Vienna, July, 1937), pp. 213–14.

AVIATION

*"Report of the A. I. M. E. Aviation Committee for the Year 1936-37," by W. E. D. Stokes, Jr. *Mining Technology* (Amer. Inst. Min. Met. Eng., New York, July, 1937). *Tech. Pub. 823;* 25 pp., 6 figs.

*"Geological Interpretations of Aërial Photographs," by J. J. van Nouhuys. *Ibid., Tech. Pub. 825;* 18 pp., 7 figs. (full-page aërial photographs).

BAVARIA

"Structure of Tertiary Strata in Bavaria," by H. Andrée. *Oel und Kohle*, Vol. 13 (Berlin, 1937), pp. 151–53. *Abstract in English in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 164 (London, June, 1937), pp. 231–32 A.

BRAZIL

*"O Cretaceo de Sergipe" (Cretaceous of the State of Sergipe), by Carlotta Joaquina Maury. *Monographias Serviço Geol. e Min.*, Vol. XI (Rio de Janeiro, 1936). 283 pp., 3 folded international correlation tables. Text and tables in Portuguese and English. 28 pls. of fossils in separate binding, 35 pp. of explanation. 8.75×10.75 inches.

CALIFORNIA

*"Paleontology of the Pleistocene of Point Loma, San Francisco County, California," by Robert W. Webb. *Trans. San Diego Soc. Nat. Hist.*, Vol. 8, No. 24 (June, 1937), pp. 337–48.

*"Santa Maria Valley—Another Great Field," by William W. Porter, II. *Petroleum World* (Los Angeles, July, 1937), pp. 24–30; 6 illus.

CANADA

"Oil Prospects along the West Flank of Turner Valley Gasfield," by J. G. Spratt and V. Taylor. *Petrol. Times*, Vol. 37 (London, April 24, 1937), pp. 537–41. *Abstract in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 164 (London, June, 1937), p. 230 A.

"Revision of the Geology of the Southern Alberta Plains," by L. S. Russell. *Canadian Inst. Min. Met. Bull. 299* (Montreal, March, 1937), pp. 185–96. *Abstract in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 165 (July, 1937), p. 266 A.

COLORADO

"The Stratigraphy of the Upper Cretaceous Rocks North of the Arkansas River in Eastern Colorado," by C. H. Dane, W. G. Pierce, and J. B. Reeside, Jr. *U. S. Geol. Survey Prof. Paper 186-K* (1937), pp. 207–32, Figs. 9–11, Pls. 64–65. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.10.

CUBA

*"Geology of the Province of Camaguey, Cuba, with Revisional Studies in Rudist Paleontology (Mainly Based upon Collections from Cuba)," by Henry James MacGillavry. Doctor's dissertation which appeared as *Geogr. en Geol. Med. Utrecht, Geol. Physiog. Reeks, 11* (Utrecht, Holland). 168 pp., text figs., 7 pls., colored map. Paper. 9×11 inches. In English.

EAST INDIES

*"Opgave van geschriften over geologie en minbouw van Nederlandsch Oost-Indie" (Annotated Bibliography on Geology and Mining in the Dutch East Indies), by N. Wing Easton. "Geologisch-Mijnbouwkundige Bibliografie van Nederlandsch-Indië," *Geol. Mijnbk. Gen. voor Nederland en Koloniën* (Delft, Holland), Deël IV, Aflev. 3–4, pp. 19–36, items 5744–5959 for years 1935–1936 (May, 1937).

FRANCE

*"Sur un horizon pétrolifere exploitable dans le Trias (Lettenkohle) a Kutzenhausen-sud, champ de Pechelbronn" (An Exploitable Petroliferous Horizon in the Trias (Lettenkohle) at South Kutzenhausen, Pechelbronn), by R. Schnaebélé. *Bull. Assoc. Française Tech. Pétrol.*, No. 39 (June, 1937), pp. 15–21.

GENERAL

*"Geological Aspects of Deep Drilling Problems," by W. E. V. Abraham. *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 164 (London, June, 1937), pp. 378–90; 3 figs.

**Petroleum Development and Technology, 1937*, by the Petroleum Division. *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 123 (New York, 1937). Papers delivered before the Division at Los Angeles, October 1–2, 1936; Fort Worth, October 8–9, 1936; and New York, February 15–19, 1937. 689 pp. 6×9 inches. Cloth. Price, $5.00, net.

**Petroleum Royalties*, Vol. 1, No. 1 (Tulsa, July, 1937). Editor Andrew M. Rowley states that this new monthly "will concern itself with every matter affecting the oil royalty business as a whole." 30 pp. 8.5×11 inches. Published by Oil Investment Publishing Company, Midco Building, Tulsa, Oklahoma. Subscription, $5.00 per year; $0.50 per copy.

"American Cretaceous Ferns of the Genus Tempskya," by C. B. Read and R. W. Brown. *U. S. Geol. Survey Prof. Paper 186-F* (1937), pp. 105–31, Pls. 27–43, Figs. 2–6. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.15.

Geologisches Wörterbuch (Geological Dictionary), by Carl Chr. Beringer. Explanation of geological expressions. For geologists, paleontologists, mining engineers, geographers, *et al.* 126 pp., 51 figs., and a summary chart. Ferdinand Enke, Stuttgart, Germany (1937).

Who's Who in Engineering, 1937. 4th ed. Edited by Winfield Scott Downs. Biographical dictionary of the engineering profession. 1,638 pp. 6×9.5 inches. Cloth. Lewis Historical Publishing Company, Inc., New York. Price, $10.00.

**Annotated Bibliography of Economic Geology for 1936*, Vol. 9, No. 2 (July, 1937). 433 pp. (1,224 titles). Bibliography with annotations of international literature relating to ore deposits, coal, petroleum, and nonmetallic products, covering the second half of 1936. Prepared under the auspices of the Society of Economic Geologists, with funds contributed by the Geological Society of America, the Society of Economic Geologists, the American Association of Petroleum Geologists, Economic Geology Publishing Company, the National Research Council, and others. Economic Geology Publishing Company, Lancaster, Pennsylvania. Price: $5.00 per year; $3.00 per number.

Minerals Yearbook, 1937, prepared by the U. S. Bureau of Mines. 1,500 pp., 72 chaps., 120 illus., complete index. Reviews mineral industry of United States and other countries during 1936. Supt. Documents, Govt. Printing Office, Washington, D. C. Price. $2.25.

**Petroleum-Vademecum* (International Petroleum Tables), edited by Robert Schwarz. 12th edition in 2 volumes (1937). Approx. 1,100 pp. Vol. I contains chemical and physical tables of weights and measures, conversion of English and American into metric measures, specific weight, viscosity conversion, and miscellaneous information such as synonyms for oil products in different countries and languages. Vol. II contains statistics on production, imports, exports, and consumption in different countries. Explanatory text in German, French, and English. Published by Verlag für Fachliteratur Ges. m.b.H., Vienna XIX/1, Vegagasse 4. Price : 50 Öst. schillings, 4 German marks, 2 English pounds, 10 American dollars.

*"Report of the Committee on the Measurement of Geologic Time," by Alfred C. Lane *et al.* Appendix A of *Ann. Rept. Div. Geol. and Geogr., Natl. Research Council* (Washington, D. C., May, 1937). 76 min. pp.

Essentials of Engineering Astronomy, by J. H. Service. xv+167 pp., 33 illus. 6×9 inches. Clothbound. "Every civil engineer, mining engineer, and geologist should be trained . . . to map accurately an area, twenty miles square or more, in an unexplored territory." Prentice-Hall, Inc., 70 Fifth Avenue, New York (1937). Price, $2.50.

*"Ablagerungskunde, Geochemie, und Erdölentstehung" (Sedimentation Data, Geochemistry, and the Origin of Petroleum), by Karl Krejci-Graf. *Bohrtechniker-Zeitung*, No. 6 (Vienna, June, 1937), pp. 145–47.

*"Review of Progress and Trends in Acid-Treating Oil and Gas Wells," by Harry F. Wright. *Petrol. Engineer*, Vol. 8, No. 10 (Dallas, Texas, 1937), pp. 124–30; 3 figs.

**Petroleum Engineer*, Vol. 8, No. 10 (Dallas, Texas, 1937). Mid-year issue containing special articles on progress and trends in drilling, production, refining, and transportation.

GEOPHYSICS

*"Phase Measurements in Electrical Prospecting," by Helmer Hedstrom. *Amer. Inst. Min. Met. Eng. Tech. Pub. 827* (New York, 1937). 18 pp., 8 figs.

*"Use of Astatized Pendulums for Gravity Measurements," by Gustaf Ising. *Ibid. Pub. 828*. 14 pp., 7 figs.

*"Correlation of Earth Resistivity with Geological Structure and Age," by R. H. Card. *Ibid. Pub. 829*. 19 pp., 7 figs.

*"A Survey of Methods for Determining Depth of Magnetic Ore Bodies," by David A. Keys. *Ibid. Pub. 830.* 8 pp., 2 figs.

*"Continuous Profiling Method of Seismographing for Oil Structures," by Sylvain J. Pirson. *Ibid. Pub. 833.* 9 pp., 5 figs.

"Observed and Calculated Values of the Magnetic Intensity over a Major Geologic Structure," by L. F. Uhrig and S. Shafer. *Beitr. zur Geophysik*, Vol. 49, Nos. 1–2 (1937), pp. 129–39. Cross section of Los Angeles Basin. *Abstract in English in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 164 (London, June, 1937), p. 233 A.

"Geo-Electrical Measurements in Drill Holes," by S. H. Shaw. *Mining Mag.*, Vol. 56, No. 4 (London, April, 1937), pp. 201–08. *Abstract in *Jour. Inst. Petrol. Tech. ibid.*, p. 232 A.

*"Micromagnetic Predictions Are Proven by Drill," by W. P. Jenny. *Oil Weekly* (Houston, Texas, June 14, 1937), pp. 110–11; 1 fig.

*"Geophysics Vs. Geology," by H. Landsberg. *Ibid.*, pp. 127–28.

*"Tektonische Forschung durch quantitative Elektrodenverfahren" (Tectonic Research by Quantitative Electrode Methods), by J. B. Ostermeier. *Bohrtechniker-Zeitung*, No. 6 (Vienna, June, 1937), pp. 158–64; 7 figs.

*"Temperaturmessungen in Erdölsonden" (Temperature Readings in Wells), by M. Schlumberger, H. G. Doll, and A. A. Perebinossoff. *Ibid.*, No. 7 (July, 1937), pp. 214–22; 9 figs. English synopsis, p. 214.

*"Progress of Geophysics," by J. Brian Eby. *Petrol. Engineer*, Vol. 8, No. 10 (Dallas, Texas, 1937), pp. 66–75; 12 figs.

GERMANY

*"Das Erdöl in Süddeutschland" (Petroleum in South Germany), by Rudolf Schreiter. *Bohrtechniker-Zeitung*, No. 6 (Vienna, June, 1937), pp. 134–44; 2 figs.

*"Das Erdöl des Zistersdorfer Oelfeldes und seine Entstehung" (Petroleum of Zistersdorf Oil Field and Its Origin), by Karl Friedl. *Ibid.*, pp. 147–57; 1 fig. Summary in English, pp. 156–57.

"Transgressions in the Upper Senonian of Hannover and the Uplift of the Hänigsen-Wathlingen and Wienhausen-Sandlingen Salt Domes," by L. Riedel. *Zeit. Deutsch. Geol. Gesel.*, Vol. 89, No. 1 (Berlin, 1937), pp. 19–44. *Abstract in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 165 (London, July, 1937), p. 271 A.

GREAT BRITAIN

*"The Overstep of the Sandgate Beds in the Eastern Weald," by J. F. Kirkaldy. *Quar. Jour. Geol. Soc. London*, Vol. 93, Pt. 2 (June 29, 1937), pp. 94–126; 7 figs., 1 pl.

*"The Geological Basis of the Present Search for Oil in Great Britain by the D'Arcy Exploration Company, Limited," by G. M. Lees and P. T. Cox. *Ibid.*, pp. 155–94; 4 figs., 3 pls.

HUNGARY

*"The Geological Conditions and Principles of the State's Oil Investigations in the Hungarian Plain and in Its Northern Ranges," by L. de Loczy. *Asvanyolaj* (Petroleum), Vol. 7, Nos. 13–14 (Budapest, July 15, 1937), pp. 85–94; 2 maps, 2 geologic sections, 1 photograph. In Hungarian. English summary, p. 85.

IOWA

**Geologic Map of Iowa*, by Allen C. Tester *et al.* Formations shown by 26 patterns in 7 colors. U. S. Geological Survey base. Scale, 1:500,000 (approx. 1 inch=8 miles). On paper sheet, 31×50 inches. Iowa Geol. Survey, Iowa City (1937). Price: flat in tube, $1.00 plus $0.15 postage; folded in envelope, $1.00 plus $0.10 postage; wall map on cloth with top and bottom sticks, $2.00, postage free.

ITALY

*"Descrizione geologica e cenni sullo sviluppo della Miniera di Vallezza" (Geology and Development of the Vallezza Oil Pool), by D. A. Greig. Reprinted by Società Petrolifera Italiana from *Atti e Memorie della R. Accademia di Scienze, Lettere ed Arti di Modena*, Ser. 5, Vol. 2 (1937). 26 pp., 3 figs., 2 pls.

"Sur le geologie des petroles Albanais" (Geology of Albanian Petroleum), by L. Maddaleda and S. Zuber. *Resumé (of article from *Azienda Italiana Petroli Albania*) by Ch. Finaton. *Revue Pétrolifère* (Paris, July 23, 1937), p. 1118.

"Les manifestations de gas hydrocarbures de la Plaine du Po" (Evidence of Petroleum Gas in the Valley of the Po), by Attilio Scichi. *La Revista Italiana del Petrolio* (July, 1937). *Abstract by Ch. Finaton. *Rev. Pétrol.* (July 23, 1937), pp. 1118–19.

KANSAS

*"Oil Development in Kansas," by Ed Bloesch. *Petroleum Royalties*, Vol. 1, No. 1 (Tulsa, July, 1937), pp. 13–14.

*"Mineral Resources of Kansas Counties," by Kenneth K. Landes. *State Geol. Survey of Kansas and Kansas State Planning Board Min. Res. Cir. 6. Bull. Univ. Kansas*, Vol. 38, No. 11 (Lawrence, June 1, 1937). 100 pp. Index map of state and small county sketch maps.

LOUISIANA

*"Origin of Glen Rose Formation Is Interesting Geologic Study," by H. D. Easton, Jr. *Oil and Gas Journal* (Tulsa, July 8, 1937), pp. 20–22; 5 figs.

MEXICO

The Geology and Biology of the San Carlos Mountains, Tamaulipas, Mexico, edited by Lewis B. Kellum. Subjects: "I. Geology of the Sedimentary Rocks of the San Carlos Mountains," Lewis B. Kellum; "II. Igneous Rocks of the San Carlos Mountains," Edward H. Watson; "III. Ore Deposits of the San Carlos Mountains," Edson S. Bastin; "IV. Geology of the Sierra de Cruillas, Tamaulipas," Ralph W. Imlay; "V. Mammals of the San Carlos Mountains and Vicinity," Lee R. Dice; "VI. Arachnida from the San Carlos Mountains," Arthur M. Chickering; "VII. Two New Tarantulas of the Genus *Eurypelma* from the San Carlos Mountains," Ralph V. Chamberlin; "VIII. Fishes from the San Carlos Mountains," Carl L. Hubbs; "IX. Some Amphibians and Reptiles from Tamaulipas," Helen T. Gaige. 306 pp., illus. University of Michigan Press, Ann Arbor, Michigan (1937). Price, postpaid, $5.00.

MICHIGAN

*"Occasional Papers on the Geology of Michigan." *Michigan Geol. Survey*, Geol. Ser. 34, Pub. 40 (Lansing, 1936). Pt. 1, "The Pleistocene History of the Tahquamenon and Manistique Drainage Region of the Northern Peninsula of Michigan, with a Foreword Discussing the Glacial History of Michigan and the History of the Great Lakes," by S. G. Bergquist, pp. 7–148; 16 figs., 27 pls. Pt. II, "The Pennsylvanian System in Michigan," by W. A. Kelly, pp. 149–226; 10 figs., 6 pls. Pt. III, "The Trenton and Black River Rocks of Michigan," by R. C. Hussey, pp. 227–57; 8 figs. Total 260 pp. 6×9 inches. Cloth. Price, postpaid, $1.50. Pt. I separate, $0.75. Pts. II and III each separate, $0.50.

*"Geology of the Crystal Oil Field," by G. E. Eddy. *Michigan Geol. Survey Prog. Rept. 1* (Lansing, July, 1936). 8 mim. pp. in paper cover. 8.5×10.5 inches. Subsurface contour map on Dundee formation, and geologic section of field.

*"Geology of Ogemaw County and West Branch Oil Field," by E. A. Newman. *Ibid., Prog. Rept. 2* (August, 1936). 17 mim. pp. Maps of surface geology, and the subsurface structure contour on Dundee; geologic section.

MONTANA

"Geology and Mineral Resources of North-Central Chouteau, Western Hill, and Eastern Liberty Counties, Montana," by W. G. Pierce and C. B. Hunt. *U. S. Geol. Survey Bull 847-F* (1937), pp. 225–70, Pls. 36–43, Figs. 57–60. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.35.

NEBRASKA

*"Correlation of the Members of the Shawnee Group in Southeastern Nebraska and Adjacent Areas of Iowa, Missouri, and Kansas," by G. E. Condra and E. C. Reed. *Nebraska Geol. Survey Bull. 11*, 2d. Ser. (Lincoln, June, 1937). 64 pp., 2 figs.

*"The Micropaleontology of the Niobrara Formation in Kansas, Nebraska, and South Dakota," by Gerald J. Loetterle. *Ibid., Bull. 12*. 73 pp., 2 figs., 11 pls. of fossils.

NEW MEXICO

*"Some New Mexico Fusulinidae," by C. E. Needham. *New Mexico School of Mines Bur. Mines and Min. Res. Bull. 14* (Socorro, 1937). 88 pp., 12 pls. of fossils, locality map, 2 tables (range of species and correlation of formations).

**A Reconnaissance and Elevation Map of Southeastern New Mexico*, by W. B. Lang. U. S. Geol. Survey, Washington, D. C. 2d ed. (1937). First edition printed in 1936 now exhausted. Covers area of 20,000 square miles east of Pecos River and south of Belen cut-off of Santa Fe Railway. Scale, 1 inch=3 miles. Single paper sheet approximately 40×64 inches. Free.

OKLAHOMA

"Geology and Fuel Resources of the Southern Part of the Oklahoma Coal Field: Part 2, The Lehigh District, Coal, Atoka, and Pittsburg Counties," by M. M. Knechtel. *U. S. Geol. Survey Bull. 874-B* (1937), pp. 91–149, Figs.

6–7, Pl. 11. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.20.

*"Possibilities in Western Oklahoma," by Glenn D. Hawkins. *Petrol. Roy.*, Vol. 1, No. 1 (Tulsa, July, 1937), pp. 6–9; 2 maps.

"Geology and Mineral Resources of Southern Part of the Oklahoma Coal Field: Part 1, The McAlester District, Pittsburg, Atoka, and Latimer Counties," by T. A. Hendricks. *U. S. Geol. Survey Bull. 874-A* (1937), pp. 1–90, Pls. 1–10, Figs. 1–5, Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.65.

PALESTINE

"Bituminous Deposits of Palestine and Syria," by R. Seiden. *Petrol. Times*, Vol. 37, No. 959 (London, May 29, 1937), pp. 703–05. *Abstract in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 165 (London, July, 1937), p. 270 A.

PENNSYLVANIA

*"Geology and Oil Resources of the Bradford Field, Pennsylvania and New York," by Charles R. Fettke. *Pennsylvania Top. and Geol. Survey Bull. 116* (Harrisburg, May, 1937). 17 pp. 5 figs.

*"Physical Characteristics of the Bradford Third Sand and Relation to Occurrence of Oil," by C. R. Fettke. *Oil and Gas Jour.* (Tulsa, August 5, 1937), pp. 20–25; 1 map, 5 figs, 6 tables.

POLAND

*"Die Gebiete und Urquellen der polnischen Erdöle und Erdgase" (The Region and Sources of Polish Petroleum and Natural Gas), by Stanislaw Olszewski. *Petrol. Zeit.*, Vol. 33, No. 26 (Berlin, July 1, 1937), pp. 1–8; 4 figs. A continued article.

*"Explanation of the Skole Sheet (Zone 52, Column 37) of the General Geological Map of Poland on the Scale of 1:100,000, Pt. 2," by K. Tolwinski. *Service Géologique des Karpates* (Boryslaw, 1937). 90 pp., cross section, and colored map (folded sheet, 21×18 inches). In Polish, with résumé in French (pp. 73–90). Map is composed of Skole sheet on the south and the southwest corner of the Drohobycz sheet on the north in order to include the petroliferous region of Boryslaw.

*"Geological Bibliography of Pologne, No. 14, 1934," by Danysz-Fleszarowa. *Service Géol. de Pologne* (Warsaw, 1936). 30 pp., items 1–216.

**Ibid.*, No. 15, 1935 (1937). 28 pp., items 217–25 supplementing the 1934 bibliography, and items 1–180 of 1935 bibliography.

**Bull. Geol. Survey Poland*, Vol. 8, No. 4 (Warsaw, 1937). 310 pp., 4 figs., 30 pls. Approx. 7×10 inches. Paper cover. Besides report of director J. Morozewicz and several biographies, it contains among others the following articles in Polish and French. "Age of Menilite Beds in the Carpathians," by L. Horwitz; "Fauna and Age of Posidonomya Beds (Piénine Zone of Klippes, Polish Carpathians)," by L. Horwitz; "Stratigraphy and Paleogeography of Lower Devonian in Polish Mittelgebirge," by J. Czarnocki; "Fish Remains Collected in Secondary Terrain of Polish Carpathians," by M. Leriche.

**Rocznik Polskiego Towarzystwa Geologicznego* (Annals of the Geological Society of Poland), Vol. 12 (Krakow, 1936). 819 pp., 28 articles in Polish, English, German, French. Illustrated. Volume dedicated to Charles Bohdano-

wicz in celebration of 50 years of scientific activity. Contains his photograph, biography, and bibliography of 182 titles. Five articles selected from this volume are the following. "Problems of Application of Seismic Reflection Methods in the Polish Eastern Carpathian Mountains in the Light of Present Investigations," by Z. Mitera, in Polish, summary in English; "Problems of Reserves of Natural Gas in Poland," by K. Tolwinski, in Polish, résumé in French; "Some Problems of Petroleum Geology," by Karol Bohdanowicz, in Polish, summary in English; "Geology of the Weglowka Area and Possibilities of New Oil Reserves," by J. Obtulowicz, in Polish, summary in English; "Horizontal Distribution of Varieties of Oil in the Polish Carpathian Oil Province," by J. Nowak, in German, summary in Polish.

ROUMANIA

"Bucsani Oilfield," by V. Zotinca. *Mon. Petrol. Roumain* (Bucarest), 38 (1937), pp. 31–43. *English abstract in *Jour. Inst. Petrol. Tech.* (London), Vol. 23, No. 163 (May, 1937), p. 192 A.

TEXAS

*"West Texas Is 'Hot Spot'," by E. N. Redden. *Petrol. Roy.*, Vol. 1, No. 1 (Tulsa, July, 1937), pp. 20–21; 1 map.

*"Possibilities of Southwest Texas," by John W. Merritt. *Ibid.*, pp. 22–24; 1 map.

Geologic Map of Texas (1937), prepared by N. H. Darton, L. W. Stephenson, and Julia Gardner. Scale, 1 inch=8 miles. In 4 sections, each 40 by 50 inches, together making a sheet 7×8 feet. Formations shown by 108 patterns in 19 colors. Prepared by *U. S. Geol. Survey* in coöperation with *Univ. Texas. Bur. Econ. Geol.*, and collaboration of the geological societies, individual geologists, and oil companies of the state. May be ordered from the Director, U. S. Geological Survey, Washington, D. C. Price (should accompany order, no wholesale rate), $2.50.

"Spirit Leveling in Texas: Part 1, Western Texas, 1896–1935," by J. G. Staack. *U. S. Geol. Survey Bull. 883-A* (1937), pp. 1–50, Pl. 1, Figs. 1–2. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.10.

TRANSYLVANIA

"Structure of Transylvania Gas Fields," by D. Ciupazea. *Ann. des Mines*, Vol. 20, No. 3 (Paris, May-June, 1937), pp. 105–06. Summary of paper in French given at Paris International Congress of Mining, Metallurgy, and Applied Geology. *Abstract in English in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 164 (London, June, 1937), p. 232 A.

VENEZUELA

**Boletín de Geología y Minería* (Caracas), Vol. 1, No. 1 (January, 1937). 90 pp., illus., maps. The English equivalent of the title of C. Wiedenmayer's paper is "Geological Report on the Coal Deposits of Coro, Miranda District, State of Falcón." These coal deposits are Lower Miocene in age and not Carboniferous as was erroneously printed in the May A.A.P.G. *Bulletin*, p. 636.

WEST VIRGINIA

**Survey of Natural Gas of West Virginia for Public Service Commission of West Virginia*, by Paul H. Price, A. J. W. Headlee, and Leonard C. Swing.

West Virginia Geol. and Econ. Survey, Morgantown (June, 1936). 63 pp., 10 tables, 39 figs. Folio form, approx. 17×14 inches.

*"The Oriskany Sand of West Virginia, Its Extent, Geology, and Significance," by J. E. Billingsley. *Oil Weekly* (Houston, July 26, 1937), pp. 14–20; 3 maps, 1 photograph.

*"Oriskany Sand Fields Create New West Virginia Operating Problems and Practices," by R. P. Walsh and J. E. Billingsley. *Ibid.* (August 2, 1937), pp. 36–42; 6 figs.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 7, No. 2 (August, 1937).

"Marine Sediments Around Catalina Island," by F. P. Shepard and W. F. Wrath.

"A Method for the Mineralogical Fractionation of Sediments by Means of Heavy Liquids and the Centrifuge," by Ernest Berg.

"Bottom Deposits of the Ross Sea," by H. C. Stetson and J. E. Upson.

"The Bottom Sediments of Lake Monona, A Fresh-Water Lake of Southern Wisconsin," by W. H. Twenhofel.

"Heavy Minerals in Illinois Sands and Gravels of Various Ages," by J. E. Lamar and R. E. Grim.

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 11, No. 5 (July, 1937).

"Upper Cretaceous Mollusca from Southern California," by Willis Parkison Popenoe.

"A New Pennsylvanian Cephalopod Fauna from Oklahoma," by A. K. Miller and John Britts Owen.

"The Lower Middle Devonian Tetracorals of the Nevada Limestone," by Erwin C. Stumm.

"The Genus *Cynarctus*," by Paul O. McGrew.

"*Euceratherium bizzelli*, a New Ungulate from Oklahoma," by J. Willis Stovall.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 9 (SEPTEMBER, 1937), PP. 1226-1237

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Thomas K. Bowles, Bakersfield, Calif.
James C. Kimble, Jack M. Sickler, William W. Porter, II

Ralph Homeward Espach, Laramie, Wyo.
J. K. Knox, W. B. Berwald, E. J. Boos

Ralph B. Ross, Pittsburgh, Pa.
Roy T. Hazzard, Victor P. Grage, B. W. Blanpied

Francis Parker Shepard, La Jolla, Calif.
Parker D. Trask, L. C. Snider, Hugh D. Miser.

FOR ASSOCIATE MEMBERSHIP

David F. Broussard, Houston, Tex.
E. E. Rosaire, C. M. Boos, J. W. Flude

John William Byers, Houston, Tex.
J. L. Tatum, J. Garst, Paul Weaver

Victor Nathaniel Fischer, Urbana, Ill.
F. W. DeWolf, H. R. Wanless, Alfred H. Bell

L. Clark Knight, Great Bend, Kan.
R. G. Moss, O. H. Hill, B. H. Richards, Jr.

James K. Rogers, Russellville, Ark.
E. L. Caster, S. A. Packard, Luther B. Smith, Jr.

Loring Bertram Snedden, Ventura, Calif.
Harold B. Rathwell, Chester Cassel, Albert Gregersen

Dean C. Wellman, Detroit, Mich.
R. L. Belknap, Theron Wasson, Charles H. Behre, Jr.

Lester Leroy Whiting, Wichita, Kan.
J. N. Troxell, Jerry E. Upp, Harold O. Smedley

FOR TRANSFER TO ACTIVE MEMBERSHIP

Charles Brewer, Jr., Charleston, W. Va.
J. E. Billingsley, William O. Ziebold, Robert C. Lafferty

SUPPLEMENTARY MEMBERSHIP LIST, SEPTEMBER 1, 1937

Members	75
‖Associates	85
Total additions since publication of list in March *Bulletin*	160

Adkins, W. S., Shell Petr. Corp., Houston, Tex.
‖Allon, Michael, Mene Grande Oil Co., Apartado 35. Ciudad Bolivar, Venezuela, S.A.
Anderson, John G., 815 Chronicle Bldg., Houston, Tex.
Andrews, Thomas G., University, Ala.
‖Baak, Jan A., Nederlandsche Pacific Petr. Mij., Medan, Sumatra, D. E. I.
‖Bailey, John J., Box 865, Midland, Tex.
Barber, Clifford F., United Production Corp., Beeville, Tex.
‖Bardeen, Thomas, Drawer 2038, Pittsburgh, Pa.
Barksdale, Julian D., University of Washington, 122 Johnson Hall, Seattle, Wash.
Bayer, H. M., Gulf Oil Corp., Fort Worth, Tex.
‖Beach, John H., Box 517, Ventura, Calif.
Beilharz, Carl F., 401 Sherman Bldg., Corpus Christi, Tex.
‖Bowser, William F., Box 1357, Abilene, Tex.
‖Bradford, Charles E., 804 Stone St., Great Bend, Kan.
‖Bradish, Beverly B., Box 758, Wilson, Okla.
‖Bramlette, William Allen, 3106 Robinson, Austin, Tex.
‖Braunstein, Jules, 531 W. One Hundred and Twenty-Second St., New York, N. Y.
‖Brehm, Clarence E., Amerada Petr. Corp., Tulsa, Okla.
‖Bryan, Carl L., Drawer 2038, Pittsburgh, Pa.
Bunn, John R., Box 1347, McAllen, Tex.
Burton, George E., Sun Oil Co., Box 623, San Angelo, Tex.
Casebeer, C. T., 1208 N.E. Nineteenth St., Oklahoma City, Okla.
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‖Cogen, William M., Shell Oil Co., Shell Bldg., Houston, Tex.
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Cole, John Gordon, Box 1200, Bakersfield, Calif.
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MID-YEAR MEETING, PITTSBURGH, OCTOBER 14–16, 1937

The Engineers Society of Western Pennsylvania and the Appalachian Geological Society of Charleston, West Virginia, join the members of The American Association of Petroleum Geologists resident in the Appalachian District in inviting the Association to hold its mid-year meeting in Pittsburgh on October 14, 15, and 16, 1937. A cordial invitation to attend this meeting and the field trips is extended to all members, associates, their friends and ladies. This will be the second meeting of the Association in the eastern states and the first one to be held in the region of the birthplace of the American Oil Industry.

MEETING HEADQUARTERS

All meetings will be held in the Urban room on the 17th floor of the William Penn Hotel. The registration booth will be in the corridor of the same floor. A separate parlor has been provided for the ladies' registration on this floor.

REGISTRATION

Members and guests are requested to register Thursday morning and meet old friends at the headquarters. Sight-seeing trips will be arranged to suit participants. There are many interesting things to be seen in Pittsburgh, including the Carnegie Museum, Cathedral of Learning, Mellon Institute of Industrial Research, U. S. Bureau of Mines, a physiographic study from the top of the Gulf Building, abandoned meanders of the rivers, sections of the coal measures, a mechanized coal mine, and the Westinghouse Electric and Manufacturing Company research laboratory and plant.

TECHNICAL SESSIONS

Technical papers have been prepared dealing with the geology of the eastern part of the United States. These will be presented in three sessions, Thursday afternoon, Friday morning, and Saturday morning. The program has been worked out and integrated so as to give a broad perspective of the geology of the eastern producing states.

THE OTHER HALF DAYS

Thursday morning.—Local trips in Pittsburgh.

Friday afternoon.—A trip will be made through the Jones and Laughlin Allequippa steel mill, where we shall have an opportunity of watching the process of making well casing.

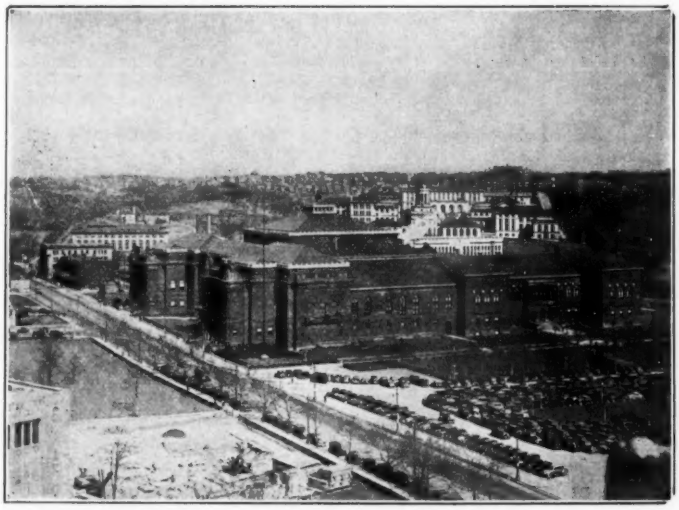
Saturday afternoon.—There is a football game between Carnegie Tech and Notre Dame. A block of 100 seats has been set aside for our use but it will be necessary to make reservations for them by September 25. Please indicate how many tickets you want at $3.30 each. Send the committee a card and do not delay.

FIELD TRIPS

The pre-convention trip will leave Pittsburgh early Monday morning, October 11. Those who take this trip will observe the peneplains and the Allegheny plateau, the gently folded foothills and the mountain front, the steeply folded Appalachian Mountains, and start up the beautiful and historic Shenandoah Valley at Winchester, Virginia. First overnight stop at New Market, with an evening trip through Endless Caverns. Continuing up the valley to Harrisonburg and thence westward across the mountains, one encounters geologic structure and scenic grandeur not surpassed anywhere. The second night stop will be at Charleston, West Virginia, where the Appalachian Geological Society has arranged a banquet, after which there will be a short informal symposium on the oil fields of West Virginia. On the third day many of these fields will be visited, including some that made history in the early days of the oil industry of America. Lunch at Sistersville. The party will arrive in Pittsburgh early Wednesday evening thoroughly primed for the technical program to follow during the next three days. Total cost of the trip,

not over $25.00 including transportation. Details will be furnished upon application. It will help the committee on arrangements if you indicate promptly on a postcard your intention to take this trip. The ladies will also enjoy it as it is a trip replete with magnificent scenery.

A post-convention trip will leave Pittsburgh on Saturday evening after the football game. Those taking this trip will spend the night in Franklin, Pennsylvania. On Sunday they will visit the Drake well, the repressuring operations at Titusville, the flooding operations at Bradford, and other oil and gas fields in northern Pennsylvania. Members may return to Pittsburgh, Sunday evening, or leave directly for home.



CARNEGIE LIBRARY AND MUSEUM, PITTSBURGH.

ENTERTAINMENT

Thursday evening there will be open house at the Engineers Club in the William Penn Hotel for members, friends, and ladies. This will include an informal reunion of old friends, card games, and a buffet supper about midnight. Compliments of Pittsburgh hosts.

On Friday evening there will be a smoker at the laboratory of the Gulf Research and Development Corporation. This will afford an opportunity for an inspection of the laboratory. Arrangements have been made for other entertainment for the ladies.

LADIES' ENTERTAINMENT

Headquarters and lounge for the ladies will be in a separate parlor on the 17th floor of the William Penn Hotel. A committee of Pittsburgh ladies has provided entertainment for the visiting ladies. There will be sight-seeing trips

to many interesting points in Pittsburgh. The Heinz Company will entertain with a 57-varieties luncheon and a trip through their plant.

On Friday evening there will be a complimentary theater party at the Nixon to see a regular stage production (name not announced yet). It is important to know early how many tickets will be needed, so please send the committee a postcard *pronto*.

HOTELS

Pittsburgh has four principal hotels downtown all within a few blocks of the headquarters hotel. There are two good hotels in the Oakland District near the Carnegie Museum. These are about 20 minutes by trolley from downtown. Following are the room rates. You are requested to make your own reservations.

Downtown	*Single*	*Double*	
		Double beds	*Twin beds*
William Penn			
(All rooms with bath)	$3.00–$6.00	$5.00–$8.00	$6.00–$9.00
Pittsburgher			
(All rooms with shower or bath)	$3.00–$4.00	$4.00–$6.00	$5.50–$6.00
Roosevelt			
(All rooms with bath)	$2.50–$5.00	$4.00–$7.00	$5.50– 7.00
Fort Pitt			
(Running water, no bath)	$1.50	$2.50	
(With bath)	$2.50	$3.50	$4.00
Oakland District			
Webster Hall			
(Running water, no bath)	$2.00	$3.00	
(With bath)	$2.50–$3.00	$4.00–$5.00	
Schenley			
(All rooms with bath)	$3.50–$5.00	$5.00 to	$9.00

GENERAL

It is hoped that a large number of the membership will avail themselves of this opportunity to visit the scenes where the oil industry of America experienced its birth and early growing pains and where the foundations of our science of petroleum geology were laid.

Please fill out and return promptly the information card enclosed with the notice mailed you. It will help the trips committee to provide transportation, lodging, and meals for those taking the trips. Furthermore, it is essential that the committee know by the 25th of September how many tickets will be required for the football game and for the ladies' theater party. They can not hold unneeded reservations longer than that, nor can they be sure of obtaining additional reservations after that date.

For further information address R. W. Clark, Appalachian District Representative, P. O. Box 1166, Pittsburgh, Pennsylvania.

ON TO PITTSBURGH!

SECOND WORLD PETROLEUM CONGRESS, PARIS, JUNE 14–19, 1937

The following is a partial list of papers on geology and general exploration presented before the second World Petroleum Congress at Paris, June 14–19. The titles of the papers have been freely translated. These and several hun-

dred other papers, with titles as diversified as the activities of the petroleum industry, made up the program.

ARGENTINA

Anon.—Geological and Mining Activity of the "Government Oil Fields"

AUSTRALIA

Arthur Wade—Recent Advances, Political and Geological, in Connection with the Search for Oil in Australia

AUSTRIA

H. Vetters and L. Waagen—Conclusion about Oil in Austria, and Its Geological Basis
D. Andrusov—Stratigraphy of the Neogene of the Intra-Alpine Basin of Vienna and Its Relation to Petroleum Deposits

BAHREIN

Anon.—Progress Report on Bahrein Islands

CANADA

G. S. Hume, P. Rosewarne, and E. H. Wait—Petroleum and Natural Gas in Canada, 1935–1936

CZECHO-SLOVAKIA

J. Woldrich—Oil Deposits in Czecho-Slovakia

DUTCH EAST INDIES

S. Van Dorsser—Development of the Petroleum Industry in the Netherlands East Indies

ENGLAND

Oil Prospecting in Great Britain by the Anglo-Iranian Oil Company

FRANCE AND COLONIES

M. Schlumberger—General Report for France
L. Bertrand and L. Barrabé—On the Presence, along the Northern Border of the Pyrenees, of a Folded Foreland Graben That Has Given Rise to Several Classical Petroliferous Formations
R. Schnaebele—Structure Map of the North Part of the Oil Fields of Pechelbronn
D. A. Schneegans—Geologic Interpretation of Petroleum Research in France
W. Bruderer—Jurassic Structures in the Region of Petitjean
J. Gubler—General Features of the Paleogeography of the Pre-riff Lias
M. Rey, V. Ostrowsky, and N. Gouskov—Studies of the Post-Jurassic Terrane and Classification of Evidences of Hydrocarbons in the Western Pre-riff
M. Tenaille—Tectonics of the Region of the Rharb
B. Yovanovitch—Bituminous Facies of the Moroccan Paleozoic
L. Joleand—General Technique and Oil Development in the Land and the Sea of Oman
L. Joleand—The Asphalt of the Region of Bone, Algeria
J. O. Haas—The Geology of the Petroliferous Basins of French East Africa
J. O. Haas—General Report for French East Africa
Vigier, F. Lassauzé, and J. Lacoste—General Report for Morocco
A. Roux and M. Solignac—General Report for Tunis
J. M. Solignac—Petrographic and Physical Study of Some Bituminous Rocks of Tunis
J. M. Solignac—Aerial and Geologic Exploration of Presumably Petroliferous Structures in Tunis
E. Berkaloff—Utilization of Airships for Geologic, Hydrographic, and Mining Mapping

GENERAL

O. Barsch—Origin of Salt Springs and Possibility of Petroleum Evidence
M. W. Strong—Micropetrographic Methods as an Aid to the Stratigraphy of Chemical Deposits
K. Krejci-Graf—Principles of the Origin of Oil
Schultze—New Contributions of Physical Chemistry to the Diagenesis of Petroleum
H. Van Hettinga Tromp—Petroleum Can Not Be Generated in Limestones
G. Delga—Analytic Study of Geologic Sections
M. F. Glassner—Practical Results and Scientific Basis of Micropaleontology

GERMANY

M. O. Barsch—The Building of the Geophysical Reich Survey
M. A. Bentz—Search for Oil in Germany with Government Aid

IRAK

Iraq Petroleum Company—Kirkuk Oil Field

IRAN

Amiranian Oil Company—Iranian Field

MEXICO

E. Diaz Lozano—Mexican Petroleum Productive Zones—Their Geological Features
W. Staub—Geologic Cross Section through the Oil Fields of Northeastern Mexico
G. Ortega—Mexican Oil Industry, Past and Present

PERU

A. Cabrera la Rosa—Petroleum Reserves of the Peruvian State
O. Quiroga—Petroleum Industry in Northern Peru
J. B. Hughes—Tertiary Microfauna of Northwestern Peru
A. Jochamowitz—Petroleum in Peru
G. Peterson—Tectonics of Tertiary Petroleum in Northwestern Peru

POLAND

K. Tolwinski—General Report for Poland
M. Kleinman—Chemical Analyses of Bituminous Substances in the Miocene Rocks of Poland
L. Mrazec—Residual Salinity of Miocene Marls of the Transylvanian Basin
T. Chlebowski and J. Czernikowski—Micropaleontological Researches in the Foreland of the Eastern Carpathian Mountains of Poland
G. Strzetelski—Petroleum Industry in the Polish Carpathians
W. Teisseyre—The Degree of Epirogenic Inclination of the Foreland from the Point of View of the Exploitation of Petroleum in the Sub-Carpathian Zone
U. V. Wysznski—Possibility of Petroleum Deposits in the Miocene of Poland

RUMANIA

G. Macovei—General Report on Geology of Rumania
A. Dragulinescu—General Report on Exploration in Rumania
P. Petrescu—Saline Waters of Rumanian Oil Deposits
D. Stefanescu—Bucsani Oil Pool

SYRIA

L. Dubertret—Geologic Conditions of Prospecting for Petroleum in Syria

UNITED STATES OF AMERICA

Anon.—Progress in Petroleum Production in the United States for the Years 1935 and 1936
E. E. Rosaire—Developments in Exploration Geophysics since 1935

VENEZUELA

Anon.—Progress Report on Venezuela for the Years 1934–1936
G. Zuloaga—General Geologic Report on Venezuelan Oil Fields with Notes on Production and Exploration

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CODE OF ETHICS OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OBJECT. The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and to encourage improvements in the methods of exploring for and exploiting these substances; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas; to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous persons posing as petroleum geologists. (Constitution, Article II.)

ARTICLE I. GENERAL PRINCIPLES

SECTION 1. The practice of petroleum geology is a profession. It is the duty of those engaged in it to be guided by the highest standards of professional conduct and to subordinate reward and financial gain thereto.

SEC. 2. The confidence of the public and of the oil industry can be won and held only by the practice of the highest ethical principles.

SEC. 3. Honesty, integrity, fairness, candor, fidelity to trust, inviolability of confidence, and conduct becoming a gentleman are incumbent upon every member of the Association.

ARTICLE II. RELATION OF GEOLOGIST TO PUBLIC AND PROFESSION

SECTION 1. A geologist should avoid and discourage sensational, exaggerated, and unwarranted statements, especially those that might induce participation in unsound enterprises.

SEC. 2. A geologist should not knowingly permit the publication of his reports or maps for the purpose of raising funds without legitimate and sound development in view.

SEC. 3. A geologist may accept for his services in the making of a report an interest in the property reported on, but it is desirable that the report state the fact of the existence of the interest.

SEC. 4. A geologist should not give an opinion or make a report without being as fully informed as might reasonably be expected, considering the purpose for which the information is desired. The opinion or report should make clear the conditions under which it is made.

SEC. 5. A geologist may publish simple and dignified business, professional, or announcement cards, but should not solicit business by other advertisements, or through agents, or by furnishing or inspiring exaggerated newspaper or magazine comment. The most worthy advertisement is a well-merited reputation for professional ability and fidelity. This can not be forced, but must be the outcome of character and conduct.

ARTICLE III. RELATION OF GEOLOGIST TO EMPLOYER

SECTION 1. A geologist should protect, to the fullest extent possible, the interests of his employer so far as consistent with the public welfare and his professional obligations.

SEC. 2. A geologist who finds that his obligations to his employer conflict with his professional obligations should notify his employer of that fact. If the objectionable condition persists, the geologist should sever his connection with his employer.

SEC. 3. A geologist should not allow himself to become or remain identified with any enterprise of questionable character.

SEC. 4. A geologist should make known to his prospective employer any oil or gas interest which he holds in the region of his prospective employment.

SEC. 5. A geologist, while employed, should not directly or indirectly acquire any present or prospective oil or gas interest without the express consent of his employer.

SEC. 6. A geologist retained by one client, should, before accepting engagement by another, notify them of this affiliation, if in his opinion the interests might conflict.

SEC. 7. A geologist who has made an investigation for a client should not, without the client's consent, seek to profit from the economic information thus gained, or report on the same subject for another client, until the original client has had full opportunity to act on the report.

SEC. 8. A geologist should not accept direct or indirect compensation from both buyer and seller, without consent of both parties; or from parties dealing with his employer without the employer's consent.

SEC. 9. A geologist should observe scrupulously the rules, customs, and traditions of his employer as to the use or giving out of information or the acquisition of interests, both while employed and thereafter; and, except as permitted by such rules, customs, and traditions or by the consent of the employer, he should not seek to profit directly or indirectly from the economic information gained while so employed.

SEC. 10. A geologist employed by a state geological survey should not permit private professional work or the holding of private mineral interests in the state to interfere with his duty to the public or to lessen the confidence of the public in the survey. The preferable course is to avoid such private work and interests.

SEC. 11. A geologist should not divulge information given him in confidence.

ARTICLE IV. RELATION OF GEOLOGIST TO OTHER GEOLOGISTS

SECTION 1. A geologist should not falsely or maliciously attempt to injure the reputation or business of a fellow geologist.

SEC. 2. A geologist should not knowingly compete with a fellow geologist for employment by reducing his customary charge.

SEC. 3. A geologist should give credit for work done to those, including his assistants, to whom credit is due.

ARTICLE V. DUTY TO THIS ASSOCIATION

SECTION 1. Every member of the Association should aid in preventing the election to membership of those who lack moral character or the required education and experience.

SEC. 2. A member of this Association who has definite evidence of the violation of the established principles of professional ethics by another should report the facts to the executive committee.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 9 (SEPTEMBER, 1937), PP. 1238-1240

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

WELDON E. CARTWRIGHT, formerly with the Humble Oil and Refining Company, Midland, Texas, is now with the Tide Water Associated Oil Company at Shreveport, Louisiana.

RAY G. GREENE has resigned from the Bolsa Chica Oil Corporation, Los Angeles, to enter the petroleum exploration department of the Union Pacific Railway, 422 West Sixth Street, Los Angeles, California.

FREDERICK S. LOTT may be addressed at the U. S. Bureau of Mines, Bartlesville, Oklahoma. He was formerly at Washington, D. C.

GROVER C. POTTER, formerly of Mission, Texas, is now connected with the Gilcrease Oil Company for part-time work and will also continue his consulting work.

WILLIAM M. COGEN, formerly with the Superior Oil Company at Midland, Texas, is now employed by the Shell Oil Company at Houston, Texas.

H. C. VANDERPOOL, formerly geologist for the Champlin Refining Company, and stationed at Shawnee, Oklahoma, has been named chief geologist for the Barnett Petroleum Corporation at Dallas, Texas.

HAROLD DELONG MITCHELL, a graduate of the University of California and the University of Washington, has joined the geological staff of the Mid-Continent Petroleum Corporation at Tulsa, Oklahoma.

MIRO S. KOVAC, who received his M. A. degree in geology at the University of Wisconsin in 1937, is working for the Empire Oil and Gas Company, Bartlesville, Oklahoma.

HOMER J. SMITH has resigned as geologist with the Magnolia Petroleum Company at Ada, Oklahoma, to join the geology staff in the College of Petroleum Engineering, University of Tulsa. He will specialize in subsurface geology.

JERRY E. UPP, member of Amerada Petroleum Corporation's geological staff in Kansas, with headquarters in Wichita, was transferred to Tulsa September 1. He is succeeded in Wichita by CHARLES AGEY, formerly at Enid, Oklahoma.

J. R. REEVES, manager of Penn-York Natural Gas Corporation, has moved from Coudersport, Pennsylvania, to 518 Jackson Building, Buffalo, New York. In addition to Penn-York he will also be connected with other Canadian and New York companies of Cities Service Company.

JAMES S. KAUFFMAN, recently with the Seismograph Service Corporation, has joined the geological staff of the Wilcox Oil and Gas Company, Tulsa, Oklahoma, as assistant to the chief geologist, T. O'D. SHELTON.

MALCOLM C. OAKES is employed as field geologist for the Oklahoma Geological Survey. His residence is 524 W. Symmes Street, Norman, Oklahoma.

ANATOLE SAFONOV, who received the degree of Master of Science at Cornell in 1937, has been engaged by the Ohio Oil Company at Tulsa, Oklahoma.

GLEN M. RUBY sailed September 18 for Buenos Aires, Argentina, to become chief geologist for the Argentine Government Oil Fields. His address is Geólogo Principal, Y. P. F., Paseo Colon 922.

JOHN M. ALDEN, supervisor of oil and gas operations for the U. S. Geological Survey, died Monday, August 16, at his home, 1619 S. Delaware Place, Tulsa.

KENNETH M. WILLSON is chief geologist of the Mid-Continent Petroleum Corporation at Tulsa, Oklahoma.

W. F. EARL is in charge of the Ardmore, Oklahoma, district office for the Ohio Oil Company.

FORREST W. HOOD is in charge of the new Enid, Oklahoma, office of the Ohio Oil Company.

R. E. SPEER, formerly in the Oklahoma City, Oklahoma, office of the U. S. Geological Survey, has been transferred to the Tulsa office as assistant petroleum engineer.

FREDERICK G. CLAPP, of Bronxville, New York, who has become vice-president of the Amiranian Oil Company and Inland Exploration Company, sailed August 17 to take charge of explorations of these companies in Asia.

THOMAS R. WARRICK has returned from Caripito, Venezuela, where he was employed by the Standard Oil Company of Venezuela. He may be addressed at R.F.D. 1, Pittsburgh, Texas.

ROBERT I. SEALE, employed by the Schlumberger Well Surveying Corporation, has changed his address from Hutchinson, Kansas, to 432 Wyoming National Building, Casper, Wyoming.

D. O. CHAPELL, formerly with the Shell Petroleum Corporation in the Ardmore, Oklahoma, office, is now with the Transwestern Oil Company, Colcord Building, Oklahoma City, Oklahoma.

MICHAEL ALLON, of Pittsburgh, Pennsylvania, has accepted a position with the Mene Grande Oil Company, Apartado 35, Ciudad Bolivar, Venezuela, S. A.

GEORGE W. CARR, formerly with the Shell Petroleum Corporation, Houston, Texas, is now with the General Geophysical Company, 2513–14 Gulf Building, Houston.

FRANK C. ROPER and JOHN D. TODD, independent geologists, formerly at Lafayette, Louisiana, have opened offices at 908 Sterling Building, Houston, Texas.

HILLORD HINSON, formerly geologist for the Interstate Royalty Corporation, Limited, Houston, Texas, is now geologist for the Harrison Oil Company, 2105 Gulf Building, Houston.

HOWARD M. KIRK has sailed from New York for Afghanistan to do geological exploration work for the Inland Exploration Company and may be addressed at Kabul, Afghanistan.

The Petroleum Division of the American Institute of Mining and Metallurgical Engineers will hold two meetings this fall: in Los Angeles, California, on October 1, and in Oklahoma City, Oklahoma, on October 7 and 8.

C. A. CHENEY, consulting geologist of Tulsa, Oklahoma, was killed in an automobile accident near Mattoon, Illinois, September 2.

The eleventh annual field trip of the Kansas Geological Society, September 3–6, drew more than 100 attendants coming from states as distant as California and Maryland.

The new address of the Tennessee Division of Geology is 124 Eighth Avenue, North, Nashville, Tennessee.

J. HARLAN JOHNSON, of the Colorado School of Mines has been making a study of the Mississippian and Devonian sediments of the Aspen district, Colorado, for the United States Geological Survey during the summer.

E. G. THOMPSON of Housh and Thompson, Inc., has moved his residence back to Houston from Tyler where he has had his headquarters for the past year.

HENRY CORTES, Gulf Coast district geologist for the Magnolia Petroleum Company, has been transferred into the geophysical department. FRED C. SHIELDS has been transferred from Oklahoma City to Houston to fill the position vacated by Cortes in the Houston office.

CLYDE MAX BAUER, park naturalist, is the author of *The Story of the Yellowstone Geysers* recently published by Haynes, Inc. Half the pages of the book are halftones of photographs taken by the publisher, J. E. Haynes.

GILBERT W. NOBLE has accepted the appointment as assistant professor of petroleum engineering at the Missouri School of Mines, Rolla.

R. B. CHENEY is with the United States Bureau of Reclamation, Austin, Texas.

THOMAS F. GRIMSDALE recently left London, England, for Tampico, Mexico, where he is employed by Cia Mex. Pet. "El Aguila," Apartado 150.

JAMES H. PAGE, petroleum engineer of Tulsa, Oklahoma, has been named as an assistant to E. G. DAHLGREN, director of oil and gas conservation division, Kansas Corporation Commission.

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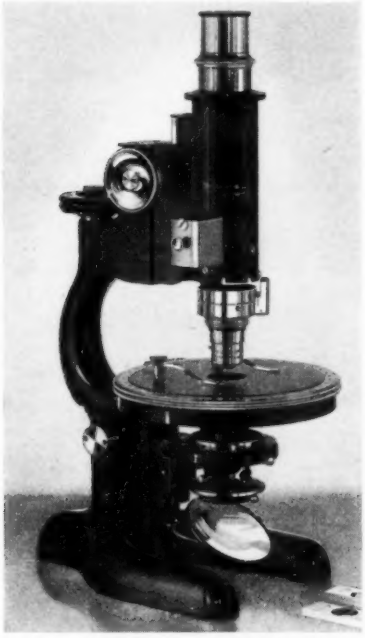

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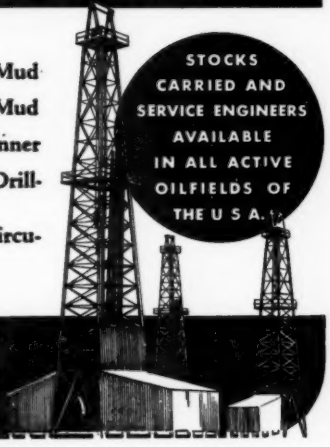

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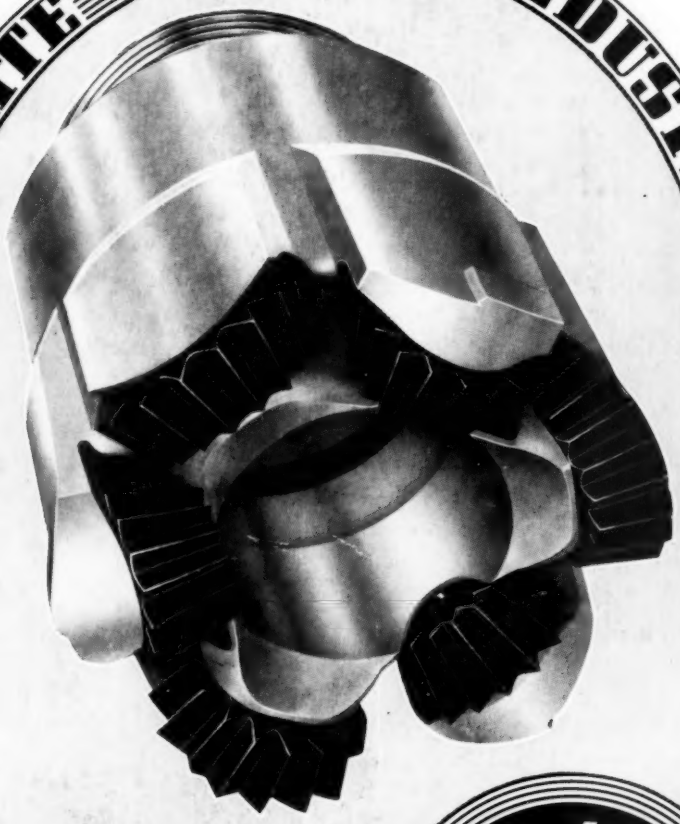

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